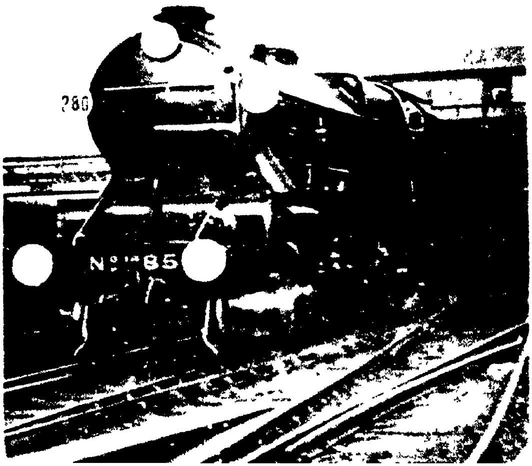


RAILWAYS OF TO-DAY

Frontispiece.

Fig. 1

First-class Restaurant Car, "Flying Scotsman" Express, L.N.E.R. (p. 220)

The [illegible] Louis XVI style; the concealed lighting and loose chairs [illegible] features of the equipment

Railways of To-Day

THEIR EVOLUTION, EQUIPMENT AND OPERATION

BY

CECIL J. ALLEN, M. Inst. T., A. I. Loco. E.

WITH TABULAR APPENDICES
OF NOTABLE ENGINEERING FEATURES,
LOCOMOTIVE TYPES, CLASSES AND DIMENSIONS,
FASTEST AND LONGEST TRAIN JOURNEYS, ETC.
EXHAUSTIVE INDEX
AND
ILLUSTRATED WITH 36 COLOURED PLATES,
A COMPLETE SECTIONAL CHART OF A MODERN
EXPRESS LOCOMOTIVE,
200 PHOTOGRAPHIC REPRODUCTIONS AND
25 DIAGRAMS IN THE TEXT

LONDON
FREDERICK WARNE & CO. LTD.
AND NEW YORK

and tabulated, and also by the tabular appendices and the complete index with which the volume concludes.

The acknowledgment of the writer is due to the following for the loan of many of the excellent photographs which have been reproduced :—British Power Railway Signal Co., Ltd., Plates 163 (left), 169 ; Canadian National Railways, Plates 19, 32, 38, 69, 113, 115, 120, 134 (top) ; Canadian Pacific Railways, Plates 11, 119 (lower), 130, 143, end-paper 3 ; Chemin de Fer du Nord, France, Plate 80 ; French Tourist Bureau, Plate 20 ; German Tourist Bureau, Plates 126, 158 ; Great Western Railway, Plates 9, 21, 55, 66, 70-72, 82, 85, 86, 87, 125, 171, Figs. 15, 16, 24 ; Grisons Tourist Office, Coire, Switzerland, Plates 14, 17, 34, 35, 42, end-paper 4 ; High Commissioner, Union of South Africa, Plates 23, 24, 26, 27, 67 (top), 129 ; London and North Eastern Railway, Plates 1, 3, 5, 8, 10, 31, 36, 37, 46 (top), 47-49, 51, 53, 60 (lower), 74, 79 (lower), 88, 93, 109, 118, 119 (top), 122 (top), 124, 148-150, 155 (top), 162 (lower), 164, 176, 179 ; London, Midland and Scottish Railway, Plates 4, 59, 60 (top), 79 (lower), 94, 98, 108, 110 (lower), 116, 117, 134 (lower), 135, 144, 147, 152, 177 ; Metropolitan Carriage Wagon and Finance Co. Ltd., Plate 107 ; Metropolitan Railway, Plates 97, 100, 101 ; Morris Tracklayers, Ltd., Plate 54 ; North British Locomotive Co. Ltd., Plate 76 ; Pullman Car Co., Plate 116 (top) ; *Railway Gazette*, Plates 46 (lower), 67 (lower), 73 ; Romney, Hythe and Dymchurch Railway Co., Plate 28 (top); Sentinel Waggon Co., Ltd., Plates 131-133, 139 ; South Australian Railway, Plates 65, 145, 151, 156 ; Southern Pacific Railway, Plates 15, 45, 84, 178, 180 ; Southern Railway, Plates 7, 29, 58, 75, 80, 89, 92, 95, 99, 105, 153, 160, 163 (right), 168, 170 (lower), 174, 175, end-papers 1, 2 ; Swiss Federal Railways, Plates 13, 16, 18, 40, 41, 103, 106, 159 . Underground Electric Railways of London, Plates 39, 43, 44, 96, 121, 138, 140-142

154, 161 (right), 167 (left), 170 (top), Figs. 20, 21 ; Westinghouse Brake and Saxby Signal Co., Ltd., Plates 50, 161 (left and centre), 166, 167 (top), 172, 173 ; W. R. Sykes Interlocking Signal Co. Ltd., Plate 165.

A special feature has been made of the colour reproduction, which is on a scale not previously attempted in any railway book. The characteristic liveries of the locomotives and rolling stock of British Railways have been set accurately on record, as well as representative views of locomotives and trains in other countries, while various other subjects affording scope for colour have been added to complete a comprehensive scheme of illustration. No pains have been spared to ensure accuracy of treatment in each coloured plate, and in this connection the help of several of the Railway Companies already mentioned deserves grateful acknowledgment. Special mention must also be made of the valuable assistance rendered by Mr. W. J. Stokoe, to whose painstaking labour in supervising the preparation and arrangement of the plates there will be largely due whatever success may be achieved by this volume.

PART IV

Railway Operation

APPENDICES

LIST OF ILLUSTRATIONS

COLOUR PLATES

DIAGRAMS

PART I

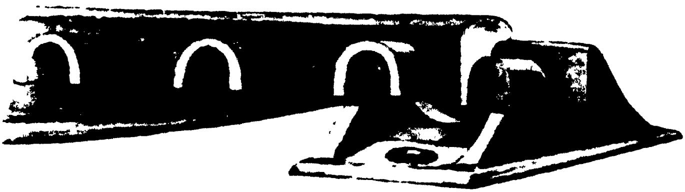
THE TRACK

up to that opening had proceeded on two distinct lines. There was, first of all, the inception of the railway itself—the iron track which, as a substitute for the rough roads of the period, enabled horses to pull far heavier loads than before. And then, at a later date, came the genesis of the steam locomotive, first designed as a "steam carriage" to run over the roads, and not until 40 years after adapted to travel on the railways which were already in existence.

Parallel lines of flat-topped stone blocks, traces of which here and there still mark the course of the old Roman roads, show that the Romans had discovered the advantage of providing a smooth surface over which the wheels of their chariots might travel. The same idea underlay the use of parallel baulks of timber, in more recent times, along tracks where heavy haulage was being carried on in horse-drawn wagons. There is evidence of such a "tramway" existing as far back as 1555, at Barnard Castle, in the county of Durham; and by 1676 such tracks were in common use for conveying coal from the Durham and Northumberland collieries to the River Tyne. The problem of prolonging the life of the timber in these timber tracks began to be solved, early in the following century, by the use of iron plates, laid over their upper surface; and in 1734 we have the first recorded use of a flanged wheel. A further development is first heard of in 1776, when a "plate-way" was laid along a tram-road at Nunnery Colliery, near Sheffield, in which the upturned flanges of right-angled cast-iron plates (Plates 2 (*a*) and 5), laid parallel, were intended to keep the wheels of the wagons running truly along the track. It is interesting to recall that our present "plate-layers," who look after the maintenance of the railway tracks, are the lineal descendants of the men who were sent out to lay down the iron plates of these

1. Early cast iron plate way (p. 4).

2. Jessop's [illegible] bellied cast iron rail and chair, 1789 (p. 5).



3. Blenkinsop's rack rail and chair, 1811 (p. 11-12).

4. Birkinshaw T rail and chair 1820 (p. 5).

Pl. 2

p. 4.

Early Railway Track.

Coat-of-Arms, London & North Eastern Railway p. 21

early plate ways, although this method of track construction has, of course, long since passed into oblivion.

The father of the railway track, as we know it to-day, is held to be William Jessop, a pupil of the well-known engineer, John Smeaton. It was probably at the latter's suggestion that Jessop, in 1789, tried the experiment, on his tram-line near Loughborough, of the cast-iron rail illustrated in Plate 2 (*b*). As will be seen, this had a broad upper table to carry the wheels, as well as a curved lower flange, for added strength; and one end of each rail was spread out into a foot, which was both spiked down to the sleepers, and also acted as a socket for the end of the next rail. These rails were in yard lengths, weighing about 40 lb. each; an example is still preserved in the South Kensington Museum. By 1797, rails were being cast without the lower flange or the feet, and were being secured, instead, in cast-iron "chairs," similarly to the later example in Plate 2 (*d*); such tracks laid in the Newcastle district, braced with transverse sleepers, show that the chief features of design of our present-day permanent way had been reached before the end of the eighteenth century.

Immediately after this the first proposal for a public railway came to maturity. It was intended to run to Portsmouth, but the first stage, for which a separate Act of Parliament was obtained in 1801, was the Surrey Iron Railway. This may fairly claim to have been the first public railway in the world, although as yet the steam locomotive was not in existence. The first section of it ran across Mitcham Common from Wandsworth to Croydon, and was opened in 1804; the second part, for which another Act had been obtained a year before, ran on from Croydon to Merstham; traces of both are still discernible at various points. Four-wheeled horse-drawn wagons were used, 8 ft. long, 5 ft. wide and 2 ft. deep (Plate 5); the revenue

Kensington. One of them is shown in Fig. 2. There is ample evidence that these models were successful; one of them he tried, in 1786, in the darkness of night, along the church path at Redruth, and the story has been handed down that the vicar, who met this unaccustomed monster of fire and steam in the course of his evening walk, imagined that he had encountered the Devil in person! It seems clear, however, that when news came to his employers

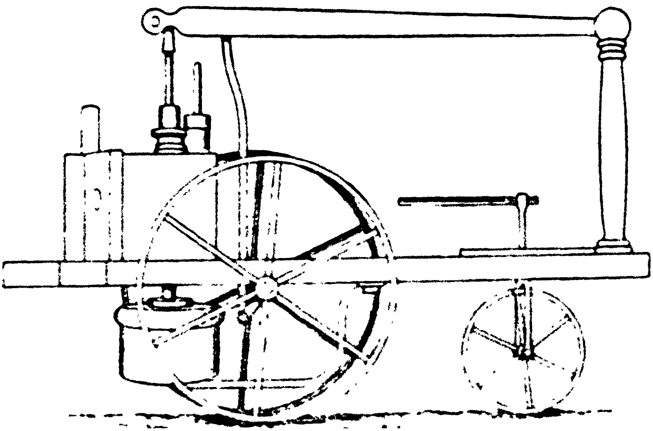


FIG. 2.—Murdock's Steam Road Carriage, 1786.

of Murdock's experiments in steam locomotion, they dissuaded him from proceeding any further, and that out of his loyalty to his firm Murdock was thus deprived of the honour which fell to Trevithick and George Stephenson.

Within a stone's-throw of the house in which Murdock lived, while at Redruth, was the residence of Richard Trevithick, a well-known Cornish engineer, and a business rival of James Watt. To what extent Trevithick knew

of Murdock's experiments is not clear, though accounts of them had doubtless come to his knowledge. It was not, however, until 1797 that Trevithick produced his first model of a steam carriage, which also is preserved in South Kensington Museum, where it may be compared with a copy of Murdock's model. There is little resemblance between the two; Trevithick's boiler and engine were in one piece, a double-acting cylinder being supplied with steam from a boiler in which the source of heat was a red-hot block of cast-iron. Various other models were made before Trevithick ventured on a full-sized steam carriage. The question as to whether smooth tyres to the wheels would afford sufficient "grip" was solved by an experiment with a post-chaise, and by Christmas Eve of 1801 the machine was ready. It was tried up Beacon Hill at Camborne, in Cornwall; heavy rain was falling and the road was rough with loose stones; but, wrote Trevithick later, "she went off like a little bird." This successful experiment led to a valuable partnership between Trevithick and his cousin, Andrew Vivian; but, far more important, it led to the building, in 1802, of the first steam locomotive (Fig. 3) designed to run on rails.

It was on February 13th, 1804, that Trevithick's best known railway locomotive (Fig. 4) made its *début* on the tramway connecting Pen-y-darran Ironworks with Merthyr Tydfil, in South Wales. It was not intended solely for tractive purposes, but did remarkably well, running with empty wagons up a gradient of 1 in 18, and hauling on the level a load of 25 tons. Nearly 5 miles an hour was the highest speed attained, though the complete journey of 9 miles, with five wagons carrying 10 tons of iron and 70 men, took just over 4 hours. The "maid-of-all-work" character of the engine is best expressed by the letter of a London engineer who was sent down to watch its working,

and wrote: "The wagon engine is to lift water in the pipes, then go by itself from the pump and work a hammer, then wind coal, and lastly to go the journey on the road with a load of coal!" One of the most striking features of Trevithick's engine was that he turned the exhaust steam from his cylinders up the chimney, and found that

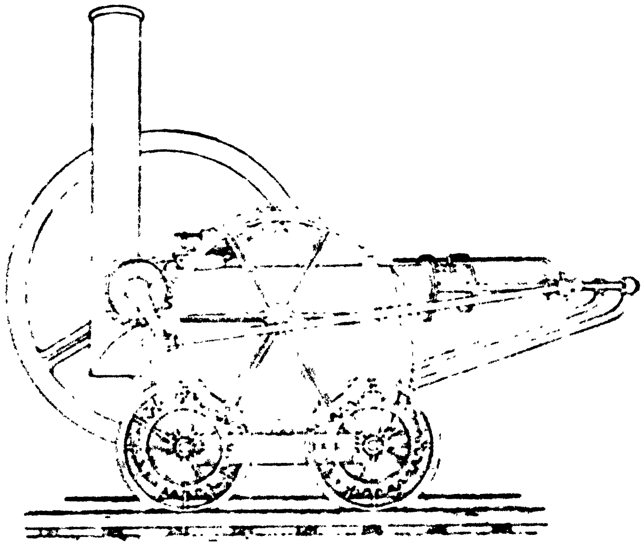
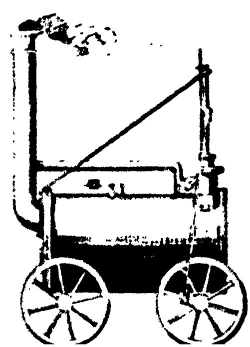


FIG. 3.—Trevithick's First Steam Locomotive, 1802.

his fire drew much better as a result. Such was the inception of the method of obtaining forced draught for the fire which is still employed in the locomotive boiler.

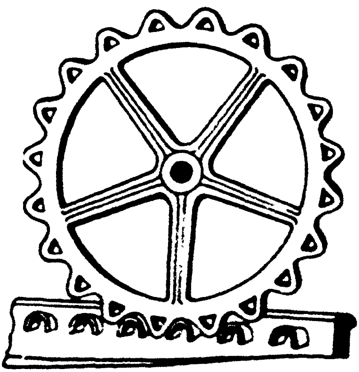
The stationary occupations of this early engine, however, were found considerably more profitable than its powers of locomotion, and its actual life as a locomotive was

short. Over several other locomotive designs of Trevithick's we have no space in which to dwell, nor over various other locomotive developments which occurred during the next twenty years. The most important of the latter was probably the patent of John Blenkinsop, agent of the Middleton Colliery, near Leeds, who, in the belief that the surfaces of smooth rails and smooth tyres did not afford sufficient adhesion for the working of heavy loads uphill, devised a method of locomotion (Fig. 5 and Plate 2 *c*) by means of a toothed driving-wheel engaging in cast projections, or "ears," at the side of the rails. This he patented in 1811. His engines were designed and built by Matthew Murray, and were the first to be driven by two cylinders. They proved themselves capable of working trains of 25 to 30 of the light wagons of the period, which, over fairly severe gradients, was good work for a locomotive of only 5 tons' weight. But the total weight moved was probably not more than 40 tons at most. The idea still survives in the "rack" railways of mountainous districts, which are described in the next chapter.



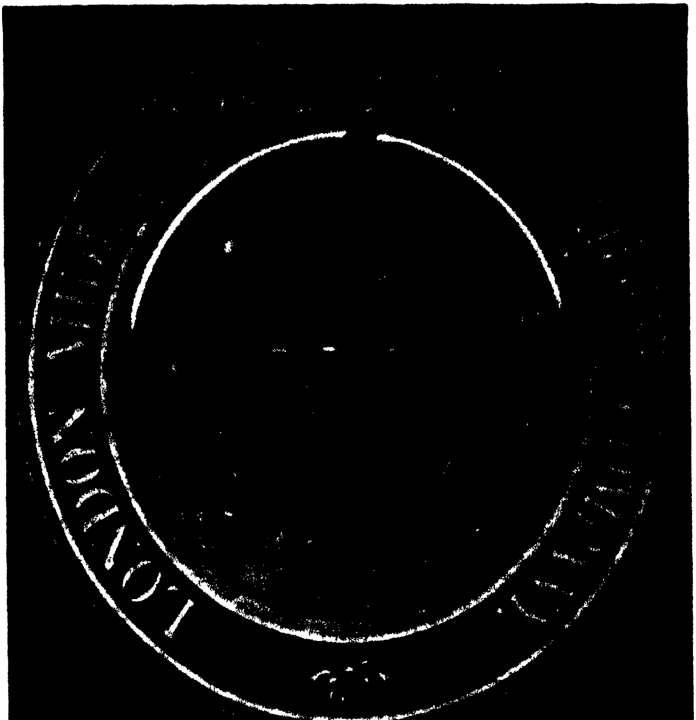
And then we come to that famous railway pioneer—George Stephenson. Second of the six sons of an agricultural labourer earning but twelve shillings a week, Stephenson started life inauspiciously enough; to his indomitable perseverance alone is due his brilliant success in life. In so much honour is the name of George Stephenson held regarding the inception of railway transport, indeed, that to-day he is often credited with achieve-

ments and inventions other than his own. He was not the inventor of the locomotive, for Cugnot, Murdock and Trevithick share that honour between them, as we have seen; he was certainly not the father of the railway, which had been in existence for decades before he came into prominence; but in the earliest days of the steam-worked railways his knowledge was so immense, his experience so varied, and his powers of organization so exceptional, that the great majority of the public lines first laid down, forming the nucleus of our present railway system, were planned, built and equipped by him, or with his active help. In the days when the opposition to railways was at its fiercest, it was George Stephenson who became the storm-centre and to whom the railwaymen looked for leadership; nor did he fail them. The world, it is safe to say, owes to George S[illegible]son more than to any other of the railway pioneers the popularisation and development of railway transport.

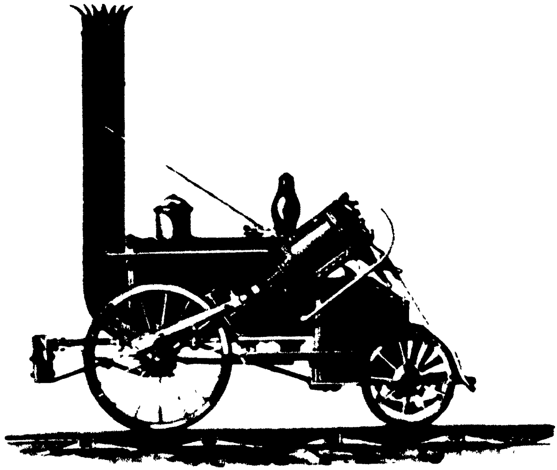


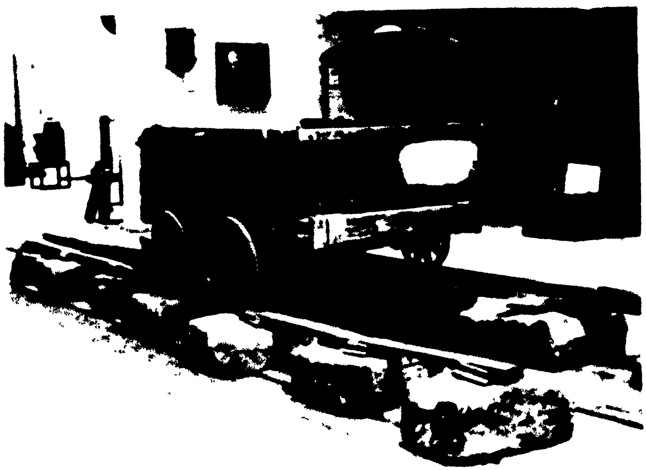
[illegible] ad Rail. 1811.

From the cottage in which he was born at Wylam-on-Tyne, in 1781, Stephenson had watched the early engines passing by on the Wylam Colliery line, including Hedley's "Puffing Billy," so called from the fierceness of its blast. This engine, by the way, is preserved, with others, in the South Kensington Museum. But it was not until 1812, when, after laboriously educating himself by every



4 Coat-of-Arms, London Midland & Scottish Railway.





in his power, he became enginewright at the Killingworth High Pit, at a salary of £100 a year, that he got the opportunity of putting his ideas in practice. He did this by building his first locomotive, the "Blucher." It was not until he had copied Trevithick's idea of turning the waste steam into the chimney that his engine could be called a success; it could now haul trains of 30 tons' weight at 4 or 5 miles an hour. But the primitive tracks of the period, coupled with the rough construction of the engine, necessitated such constant repairs as to make locomotive haulage more costly than horse traction.

"Killingworth No. 2," Stephenson's next engine, was an improvement on the "Blucher"; and with these and subsequent engines Stephenson began to bring himself under notice. His greatest opportunity—the foundation, indeed, of his subsequent career—came when Edward Pease appointed him engineer of the Stockton and Darlington Railway, in 1822. He was now in the prime of life, at 41 years of age. And when, three years later—the actual date, to be precise, was September 27th, 1825—the first steam-worked public railway in all history was opened for traffic, Stephenson was the central figure of that day of rejoicing. He had planned and laid the line; he had designed every detail of its equipment, and built its first locomotive; and his own hand was at the regulator. Though but 6½ tons in total weight, with its tender, Stephenson's "Locomotion No. 1" succeeded in working a train of no less than 38 vehicles, and attaining a speed as high as 12 miles an hour, on the inaugural run. This famous locomotive has been carefully preserved, and may to-day be seen on a pedestal in the Bank Top Station at Darlington, within less than a mile of the route over which it made its *début* more than a century ago. To-day the Stockton and Darlington Railway

forms a part of the great London and North Eastern system.

But steam locomotion was still in little more than an experimental stage. For a considerable time horse-drawn vehicles disputed with Stephenson's "Locomotion" the right-of-way over the Stockton and Darlington Railway. The opening of the Liverpool and Manchester Railway five years later, however, proved the country-wide advertisement that was needed of the practicability of railway transport with steam-hauled trains. In 1829, shortly before opening, the directors of the line offered a prize of £500 for the locomotive which should best fulfil certain conditions that they had laid down. For five days continuously it must draw behind it a train of 20 tons at 10 miles per hour; it was not to carry a steam pressure of more than 50 lb. per sq. in., nor to weigh more than 6 tons, nor to cost more than £550. Against three competitors Stephenson's "Rocket" (Plate 5) triumphantly succeeded in fulfilling these conditions and considerably more; not only were 35 miles covered with the test train in 1 hour 50 minutes, but a maximum speed of 29 m.p.h. was attained by the engine when running light.

By now the principle of railway transportation was firmly established. Every possible effort had been made by those interested in other forms of transport, and many of the landowners, to vilify the locomotive and to discredit the railway pioneers, George Stephenson in particular. Unmanageable horses, terrified cattle, suffocated birds, frightened children, destroyed vegetation, a devastated countryside—all these were to result from the use of steam engines. Yet in the very first year of its working, the Liverpool and Manchester Railway, whose actual cost of construction was three times the estimate of £400,000, was able to declare a dividend of 8 per cent. on the larger

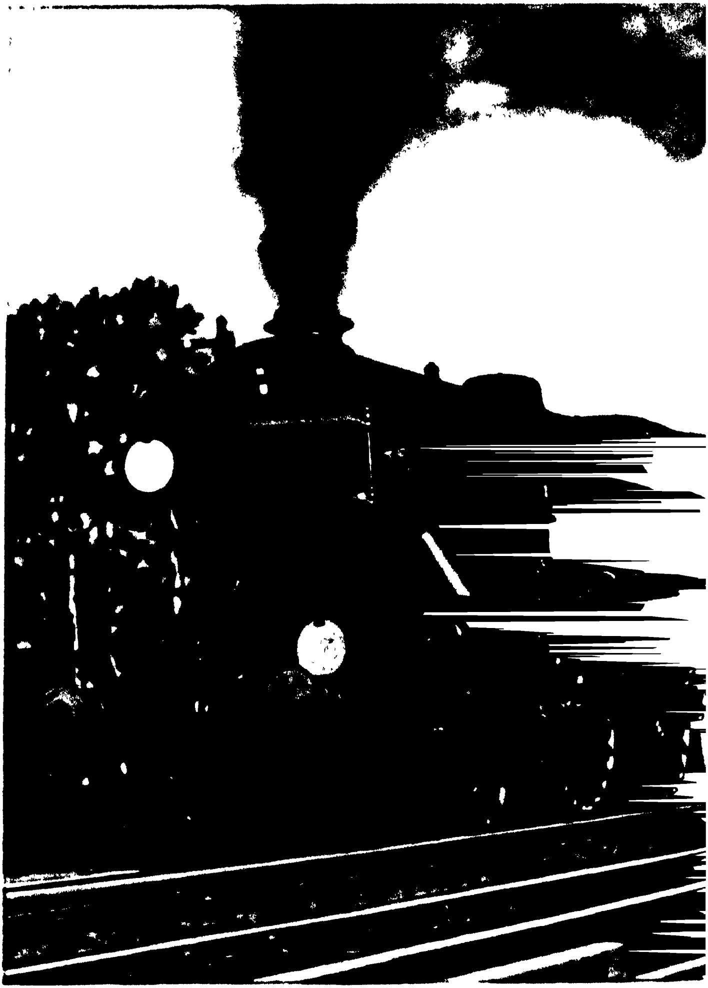
amount. And ere long, such became the fever to build railways in every direction, that in the year 1846 no less than 1,263 Bills seeking authority to construct railways were presented to Parliament for sanction. Only 120 of these proposals actually became law; but the "Railway Mania," as it was called, is a striking witness to the extraordinary hold that the railway took on the popular imagination during the two decades after the opening of the Stockton and Darlington line.

A book considerably larger than this would be needed to deal with railway history, both in Great Britain and in other countries, between that period and this, but it is necessary to mention some of the more important happenings. One by one the various sections of our great railways came into existence. The first portion of the London and Birmingham Railway was inaugurated in 1837, and by the following year the line had been opened throughout. It is on record, in the early days of this line, that when the railway authorities were approached to allow the carriage of coal over their route, one of the directors exclaimed that there was but one lower depth to which his railway could sink—the carriage of dung! When at last consent was given, a high screen was erected between the main line and the Grand Junction Canal wharf at Weedon, where the coal was transferred from barges into the railway wagons, to hide the operation from the scandalized eyes of the passengers, while the wagons themselves were sheeted over for the same reason. To-day the total amount of coal and coke carried yearly by British railways amounts to nearly 200,000,000 tons, and the revenue of £35,000,000 derived from its carriage forms the backbone of railway receipts.

The London and Birmingham formed the nucleus of the late London and North Western Railway, although that

title was not assumed until 1846, when the former was amalgamated with the Grand Junction and Manchester and Birmingham Railways. Meanwhile the first section of the Great Western Railway had been opened from Paddington to Maidenhead in 1838, and the continuation to Bristol in 1841. Brunel, its engineer, had chosen a "broad gauge" of 7 ft., in preference to the gauge of 4 ft. 8½ in. which had already become standardized in other parts of the country, and the "Battle of the Gauges," which raged through the 'forties and the 'fifties, was a contest between the protagonists of "broad" and "narrow" gauges as to which was in the right. Ultimately, as described in Chapter III, the Great Western had to bow to the inevitable, and, at enormous expense, to reduce its gauge to conformity with the standard. It was over the Great Western line that Queen Victoria made her first journey, travelling from Slough to Paddington in 1842, and the recognition that this event early afforded of the safety of travel by railway was deserved by the Great Western, in that that company had been the first to instal the electric telegraph, on Cook and Wheatstone's system, between Paddington and West Drayton in 1838. A later and most valuable contribution to the safety of railway travel was Saxby's system of interlocking points and signals at junctions, introduced in 1856.

It was not until 1850 that the Great Northern main line was opened throughout to York; even then the London terminus was at Maiden Lane, the present King's Cross terminus being first used in 1852. It is of interest to note that the clock in King's Cross tower—the only chiming clock at any British station—came from the Great Exhibition in Hyde Park of 1851. At first King's Cross had no St. Pancras terminus as a neighbour. In these early days the Midland Railway was confined to the Midlands,



Dover Pullman Boat Expre

connecting at Rugby with the London and North Western, the first through railway route from London to Newcastle-on-Tyne, indeed, was from Euston, through Rugby, Leicester, Chesterfield, Rotherham and York. By 1858 the Midland had extended southwards to Bedford, and on from there to a junction with the Great Northern at Hitchin, the Great Northern being compelled, willy-nilly, to allow the use of its metals from Hitchin into King's Cross to the Midland Company, in virtue of running powers which Parliament had granted to the latter company. This state of affairs lasted for ten years, until the opening of the Midland extension from Bedford into St. Pancras terminus in 1868.

In their efforts to popularize the Midland route, the directors of that company took a step of vast importance four years later. In 1872 both the Midland and the Great Eastern decided that third-class passengers should be admitted to all trains, including the best of the express and mail trains. All the other British lines had, ultimately, to follow suit, and the result has been the gradual, but by now almost complete disappearance of second-class in Britain. The following decade witnessed the introduction of the creature comforts of travel which have now become so commonplace as to be expected by the passenger on all the chief main line trains. The first British sleeping carriages came into use on the West Coast Route to Scotland in 1873. Next came the Pullman car, which was already well established in the United States; the Midland was the first line to introduce Pullmans, in 1875, but when other railways, such as the London, Brighton and South Coast, brought the Pullman car into extensive use, the Midland, strangely enough, abandoned them, and the bodies of the old cars, now used for staff purposes, may still be seen at various points beside the Midland line. What is now the

ubiquitous dining car followed in 1879, brought into use by the Great Northern Railway between London and Leeds. Both at that time and until long afterwards passengers desiring meals had to take their seats in the cars, as corridors were as yet unknown; it was not until 1892 that the Great Western Railway brought the first corridor trains into use.

The last two decades of the nineteenth century were marked by a considerable increase in the speed of British express trains. Competition in particular between the East and West Coast Routes to Scotland culminated in the "Race to Edinburgh" of 1888, and again in the "Race to Aberdeen" of 1895, which were amongst the most thrilling happenings in all railway history. The first of them resulted from the announcement by the Great Northern Railway, late in 1887, that in future it would carry third-class passengers on the "Flying Scotsman"; accelerations of times by both routes followed in June and July of 1888, as well as running before time, until at last the East Coast train reached Edinburgh, on August 28th, in 7 hours, 29 minutes from King's Cross. This time was a clear ¾-hour below the best times operating to-day between the same two places. After that matters settled down more normally, until the opening of the Forth Bridge in 1891, and the drastic accelerations that it made possible of the times by the East Coast Route to Dundee and Aberdeen, provoked another race.

The "Race to Aberdeen" did not break out until the summer of 1895, but the times finally achieved left those of 1888 entirely in the shade. Acceleration followed acceleration, at last almost daily, until, on the two culminating days, the East Coast covered their 523½ miles from King's Cross to Aberdeen in 518 minutes, while, on August 22nd, the West Coast Companies actually ran their 8 p.m. express

Pl. 7. C 18.

Forty years of Locomotive Development, Southern Rly. (p. 11)

Stroudley 0-4-2 locomotive "Gladstone" (1882) and 4-6-0 express locomotive [illegible] "[illegible] Nelson"

1. S. C 19.

Fifty years Locomotive Development on the L.N.E.R. (pp. [illegible])

over the 540 miles from Euston to Aberdeen in 512 minutes. The latter train was reduced in weight to 70 tons for the occasion, but even this does little to dim the lustre of the achievement, in consideration of the limited power of the engines of the period, as the throughout average speed of 63·3 m.p.h. included stops at Crewe, Carlisle and Perth, and the negotiation *en route* of Shap and Beattock Summits, respectively 915 and 1,015 feet above sea level. From that time forward the East and West Coast Companies agreed together not to cut the Anglo-Scottish train times below certain minimum figures, and that agreement still holds good. It alone can explain the somewhat surprising fact that our Scotch expresses of to-day are by no means the fastest trains over the routes that they follow, and that it is impossible, in fact, to reach any Scottish city from London at an average speed of as much as 50 m.p.h. Aberdeen, reached by the racing trains in just over 8½ hours from London in 1895, is to-day roughly 12 hours distant. In the course of time it is to be hoped that this blemish on our British train services may be removed.

The most important railway event of last century remaining to be mentioned was the coming of the Manchester, Sheffield and Lincolnshire Railway to London in 1899. This had previously been an important cross-country railway, connecting Grimsby and Sheffield, in the east, with Manchester and Liverpool, in the west, and covering intermediately large areas of the Yorkshire and Lancashire coalfields and manufacturing districts. Its southernmost tentacle extended to Annesley, in the neighbourhood of Nottingham, and in face of strenuous opposition from the other northern railways, the Act of Parliament was obtained to extend this line for a hundred miles southwards, to join the Aylesbury line of the London Metropolitan Railway at Quainton Road Junction. The same Act authorized a

change of the railway's name to "Great Central Railway." This was the last of all the great railways to come to London.

Early in the present century there came the Great War, and control of the whole of the railways of the country was immediately assumed by the Government, although the actual working was vested in a Railway Executive Committee, composed of the railway managers. By degrees the train services were cut down, gradually at first and then mercilessly; such facilities as restaurant cars were almost entirely withdrawn; speeds were greatly reduced; many stations were closed; cheap fares were withdrawn and ordinary fares were increased; relaying of lines and building of rolling stock—except for war use—were brought practically to a standstill; and other changes, too numerous to mention, had a vast effect on the working of our railways. The result, in particular, of heavy increases in wages and shortening of hours, which came about during the war, was such that at the conclusion of the four war years, in 1918, it became clear that a number of the railways serving poorly-paying territory would have great difficulty in carrying on under the new conditions. This was the genesis of the vitally important "Railways Act" of 1921.

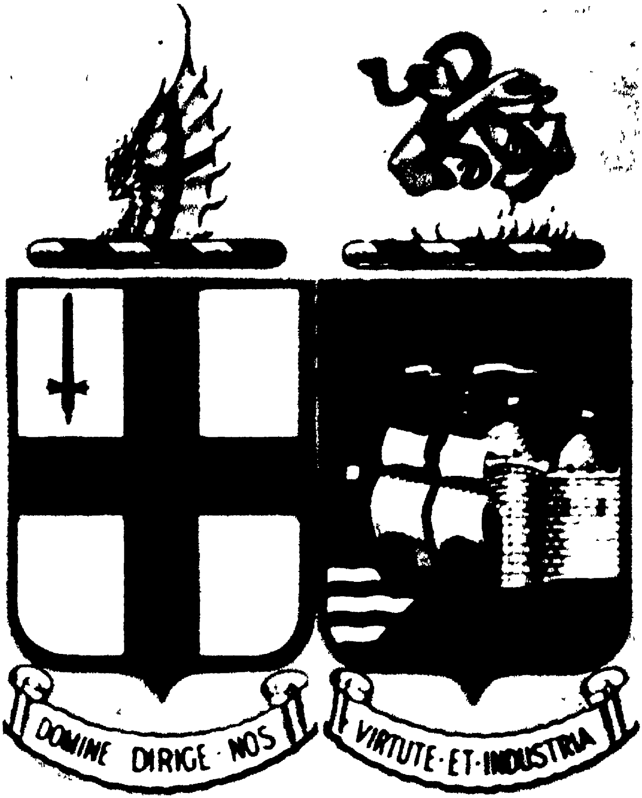
By its provisions, which became effective at the beginning of 1923, the whole of the railways of the country—with the exception of the London electric railways, and certain of the bigger "joint" railways, such as the Cheshire Lines, Midland and Great Northern, and Somerset and Dorset—were fused together into four enormous groups. The "Big Four," as they are sometimes called, are the London, Midland and Scottish and London and North Eastern Railways, running northwards from London; the Great Western, running westwards; and the Southern,

covering the major part of the Southern Counties. Their relative size is in this order. The L.M.S. combined the London and North Western and Midland Railways in England with the Caledonian, Glasgow and South Western and Highland in Scotland ; the L.N.E.R. was a fusion of the Great Northern, Great Eastern, Great Central and North Eastern in England with the North British and Great North of Scotland ; the Southern combined the London and South Western, London, Brighton and South Coast and South Eastern and Chatham ; and the Great Western was the least changed of all four from its original condition, the grouping in this case consisting merely of the absorption of a number of minor lines, such as the Welsh Cambrian, Taff Vale, Rhymney, Barry and others. The coats-of-arms of the L.M.S., L.N.E. and G.W. groups figure in colour in Plates 4, 3 and 9 respectively ; the fourth—the Southern Railway—has not yet had a coat-of arms designed. It is not possible to spare more space for the fascinating study of railway history, but it may be pursued by the student with the aid of many books which have been written on the subject, as well as by visits to the Science Museum at South Kensington, London, and to the museum established by the L.N.E.R. at York (Plate 10) to house a unique collection of railway relics.

To those unacquainted with them, the statistics in regard to the railways of Britain are almost unbelievably big. Nearly £1,200,000,000 sterling has been spent in the laying and equipment of the 23,765 route miles of track which exist in the British Isles. The total revenue of British railways in 1927 was £227,000,000, and the expenditure £185,000,000, some £40,000,000 of which was laid out on the maintenance and renewal of track and rolling stock. The "big four" alone conveyed 1,300,000,000 passengers, excluding season ticket holders, and the total number of

passenger journeys in the country was probably between 2,000 and 2,500 millions. To do this service, the passenger and freight train mileage run by the four large groups totalled 375,000,000 miles, or roughly equivalent to two journeys to the sun and back. Some of the minor statistics, too, are astonishing, such as the 280,000,000 gallons of milk conveyed in a year over the railways, or the 7,600,000 meals served in the restaurant cars, or the £2,000,000 sterling spent annually in the maintenance of signalling equipment, which is contributory to the fact that railway travel in Great Britain is safer than in any other country in the world.

One-half of the total railway mileage of the world is laid in the American Continent, the United States alone claiming 251,700 miles, while Canada follows with 40,400 miles. Germany, with 38,750 miles, claims more than the whole of British India (38,050 miles), and the African Continent (33.550 miles) only just beats France, with 33,200 miles. Russia (30,750 miles) and Australasia (26,150 miles) then head the British Isles, with 23,765 miles. Belgium, with her ramified railway system, has the longest mileage in proportion to her population, and China, very backward in her communications, has by far the fewest lines. As previously mentioned, the total extent to which the "iron trail" has been laid in every part of the world amounts to a little under 750,000 miles, and this is the fruit of but one century of railway development. It is but seldom now that we hear of new railways being laid down in the British Isles, but in other lands, and especially in undeveloped countries, that development is still going on. Despite the increasing competition of the roads and of the air, the railways have still before them a long lease of life and of usefulness.



Coat-of-Arms, Great Western Railway

CHAPTER II

Planning the Route

THERE are few operations in the realm of engineering that call for more skill and careful thought than the work of railway planning. Many and varied are the considerations that must be weighed, one against another, in the mind of the railway engineer ere he finally decides on the route to be followed by his railway, or, alternatively, that there is no possibility of laying a line which will prove a financial success. It is not that the alternative mentioned often happens. Indeed, when one looks around at some of the railway locations of to-day—the main lines through the Swiss Alps, for example, or the "funicular" ascending to the eternal snows of Jungfraujoch, over eleven thousand feet above the sea, or the railway which reaches out for a hundred miles across the sea to Key West, off the Floridan coast of the United States, or, yet again, the labyrinthine tunnels of London's tube system—it would seem that nothing is impossible to the railway engineer.

What, in brief, are the considerations by which the planning of a railway must be governed? First, and most obvious of all, the route must be the shortest practicable between the two points to be connected, except in so far as deviations may be desirable in order to tap additional sources of traffic. Then the gradients must be as flat as reasonably possible, as the cost of working the line will go up disproportionately to each increase in the

severity of the grading. But here Nature herself takes a hand in the game, and by the " lie " of the country introduces forcible modifications of the engineer's plans. By the free use of deep cuttings and high embankments, lofty viaducts and long tunnels, the engineer may succeed in laying a tolerably flat line through hilly country, but his costs of construction will go up by leaps and bounds at the same time, and unless heavy traffic is likely to materialize over the new route, it will never be possible by profitable operation to pay interest on the excessive capital expenditure involved.

In mountainous country, of course, the engineer has no option but to carry his line up the valleys, very often tunnelling under the crest of the watershed in order to reach a valley on the farther side of it which will carry him forward. The problem in such cases is by no means simple, as we shall see; the floors of these valleys often rise so rapidly that the railway engineers have been forced to desperate expedients in order to lift their lines with equal rapidity, and yet without departure from gradients which shall be surmountable by ordinary adhesion methods. Railway engineering among the mountains will be dealt with in more detail at the end of the chapter, but meanwhile it may be added that, in any hilly country, following the course of a river valley in general offers less in the way of engineering difficulties to the railway-builder than a location which cuts transversely across the parallel valleys of a watershed.

The main considerations in railway planning are therefore constructional cost, operating cost and the probable volume of traffic which will be carried over the line when complete. Operating cost is governed chiefly by the severity of the gradients along the route. Constructional cost is ruled mainly by the nature of the country to be traversed,

the most expensive construction being that entailed in carrying reasonably flat gradients through mountainous country, or, if the cost of land be included, railway-building through towns and cities. Increased constructional cost is permissible if there is reasonable prospect of the completed line carrying heavy traffic and so paying interest on the capital expenditure involved. On the other hand, operating cost need not weigh so heavily in the mind of the engineer if the traffic likely to be conveyed is but small.

The question of gradients is one of vast importance to any railway. As they increase in severity, they not only limit the loads which can be hauled by the locomotives, but also the average speeds permissible over the line. In this connection it should be remembered that on a sharply undulating road it is impossible to recoup by high speeds downhill the time lost by low speeds uphill; on an average speed of 60 m.p.h. overall, for example, if the speed drops to 40 m.p.h. up 5 ascending miles, a speed of 120 m.p.h. would be required over the next succeeding 5 miles downhill, to maintain the mile-a-minute average. But it is the question of train-loads that is the more important of the two; limited loads mean more locomotives and more train-crews, so that the cost of freight train working, in particular, is governed directly by the relative steepness of the gradients.

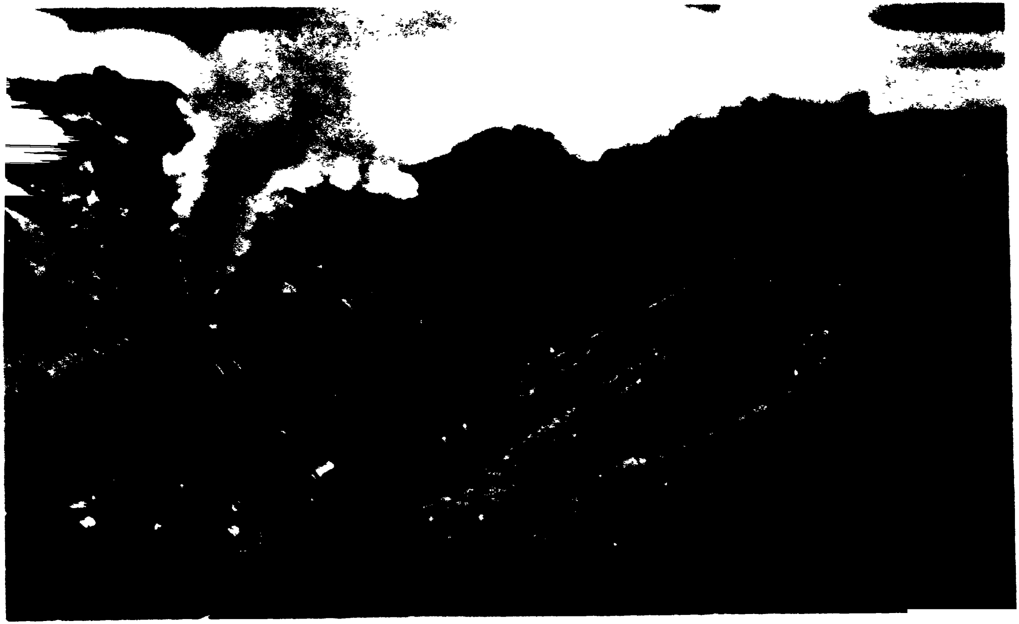
In the case of main lines carrying fast and frequent passenger and heavy freight traffic, grades of 1 in 300 and flatter may be regarded as easy, 1 in 200 is a reasonable limit of severity, especially if it is found in lengthy unbroken stretches, and 1 in 100 is steep. The West Coast main line of the L.M.S. has, for the first 150 miles of its length, no gradient steeper than 1 in 328, save the steep ascent of 1¼ miles at 1 in 70 to 1 in 105 from Euston ter-

minus to Camden; at the opening of the London and Birmingham Railway, an engine-house was installed at Camden, and by means of ropes the trains were hauled up this incline; such assistance, however, has long been done away with, although it is customary to allow the heavier trains the help of a banking engine in rear to Camden, in order to avoid loss of time and possible "stalling" on the grade. The 1 in 42 grade from Queen Street station in Glasgow up to Cowlairs was worked by rope haulage until much more recent years, but here again the help of bank engines in rear has now replaced the stationary engine. Similar assistance is given out of St. Pancras—the London terminus of the L.M.S. Midland Division—and out of the Waterloo and Victoria terminals of the Southern Railway. At the last-mentioned it is specially necessary, owing to the 1 in 61 grade which leads right off the platform ends up to the Grosvenor Bridge over the River Thames (Plate 6).

The Great Northern main line of the L.N.E.R. is another route with a bad start out of London—1¾ miles at between 1 in 105 and 110 up to Holloway, with the added complication of two tunnels in which the atmosphere is damp and the rails are invariably greasy—but after that nothing worse than 1 in 200 is met with for all but 250 miles, save two short stretches at 1 in 178. Further north, gradients steeper than 1 in 200 on to Edinburgh are confined to 27½ miles in all, the worst of which is the famous Cockburnspath bank, coming southward from Dunbar for 4½ miles up at 1 in 96, at a point where the line turns inland to avoid a coastal detour round St. Abb's Head. Even though some of its 1 in 200 banks are lengthy, and necessitate hard locomotive effort with passenger express trains up to 500 tons and freight trains up to 1,000 tons and over in weight, the East Coast route may be regarded as well-

P. 11

The entrance to Connaught Tunnel, Canadian Pacific Rly.



The English Mail Express, Great Southern Railways of Ireland (5ft. 3in. Gauge) (p. 49)

graded throughout, and it is certainly the easiest of the three routes to Scotland.

The West Coast route, apart from one or two short and sharp ascents in the neighbourhood of Warrington, Wigan, Preston and Lancaster, does not become really severe until after the shores of Morecambe Bay have been skirted, between Lancaster and Carnforth. From Carnforth the line rises for 31 miles to an altitude of 915 ft. above the sea at Shap Summit, and then drops, in a corresponding distance, practically to sea level at Carlisle. Passing into Scotland over the old Caledonian main line, the railway has then to climb in the course of 50 miles to an altitude of 1,015 feet at Beattock Summit, falling again, in just over the same distance, to heights but little above sea level at Edinburgh and Glasgow.

The bearing of grading on operating cost is brought home forcibly by the working over these two summits. Of the ascent to Shap, the steepest part is 4½ miles at 1 in 75, just below the summit, followed by seven miles descending at 1 in 125 from Shap Station to Clifton. Beattock Bank is far worse, with 10 miles continuously at between 1 in 69 and 1 in 88. Certain express trains which run combined between Euston and Crewe are therefore divided north of Crewe or Preston; or, more frequently, trains which have made the earlier part of the journey with one engine may have to be "double-headed" over these mountainous lengths. So far as Beattock Bank is concerned, a number of banking engines are kept constantly in steam at Beattock Station, and every train going north, apart from those which are piloted throughout from Carlisle, or passenger expresses headed by engines of the "Royal Scot" type, has to stop at Beattock in order to obtain rear-end assistance up to Summit. Similar assistance is available at Oxenholme, Tebay and Carlisle

for the Shap climbs in both directions, but owing to the lesser severity of the gradients in the case of Shap, is only needed, in the ordinary course, by freight trains.

Considerable altitudes are also attained by the trains over the old Midland route from London to Scotland, chief among which is Ais Gill summit, among the Westmorland Fells between Leeds and Carlisle, 1,167 feet above the sea. Expresses by the "Waverley" route to Edinburgh, continuing from sea-level at Carlisle, have then to climb to 880 feet at Whitrope, to drop sharply into the valley of the Teviot at Hawick, run across to the Tweed valley at Galashiels, climb to 900 feet at Falahill, and then fall down further tremendous grades into Edinburgh. The "ruling" or steepest gradient over this section is 1 in 70, sometimes for miles on end, with the result that the powerful "Atlantic" locomotives used on the passenger service are limited to 290-ton trainloads, as compared with 400 tons over other parts of the late North British system, which are themselves quite heavily graded. Further, in planning lines such as these, the engineers are compelled to curve their track location to such an extent, in order to conform as far as possible to the configuration of the mountain valleys and so to avoid unnecessary constructional expense, that downhill speeds from these summit-points must be severely limited, for safety's sake, and overall average speeds, even of express trains, do not greatly exceed 40 miles an hour. The highest British railway summit, on a main line, is the 1,484 feet of the Highland section of the L.M.S. at Drumochter, between Blair Atholl and Kingussie, on the Perth to Inverness line; other British railway summits in excess of 1,000 feet altitude figure in Appendix A. The steepest British gradients over which passenger trains are worked are the Causewayend and Commonhead inclines of the L.N.E.R., near

Coatbridge, both inclined at 1 in 23, closely followed by the 1 in 27 of Werneth incline, leading from Middleton Junction on the L.M.S. up to Oldham, in Lancashire.

There is not much scope in these islands for laying the perfectly straight and perfectly level line which is the ideal railway location. The combination of both is most nearly approached by the North Eastern main line of the L.N.E.R., north of York, where the track is dead straight for 30 miles, and has no gradient steeper than 1 in 624 for 39 miles. But this would make a poor comparison with the Trans-Continental Australian line connecting West Australia with the Eastern States, which for exactly 10 times the same distance—300 miles in all—is dead straight and dead level across the waterless Nullarbor Plain. For perfect straightness the 50 miles of the South Eastern section of the Southern, from Redhill through Tonbridge to Ashford, would want some beating in this country, although the stretch of line concerned is not entirely level. For entire absence of gradients, on the other hand, the Great Western Railway holds the British record, with Brunel's 160 miles of line from Paddington through Reading, Didcot, Swindon, Bath and Bristol to Taunton. Of this only 3½ miles—between Swindon and Bath—are as steeply inclined as 1 in 100, and only 3 more, through the Box Tunnel, are at between 1 in 100 and 1 in 200; the "ruling" grade over the major part of the remainder is at 1 in 1320. It is over this level stretch of line that the fastest G.W.R. schedules operate, such as 75 minutes for the 77.3 miles from Swindon to Paddington, 105 minutes for the 106.9 miles from Paddington to Bath, and others.

Brunel preserved this evenness of grade by avoiding the hills in his track location, carrying his line first up the valley of the Thames, then across to the valley of the Bristol Avon, and so down the southern shore of the Bristol

Channel. In later years the circuitousness of the route so entailed proved a serious handicap, and between the years 1900 and 1910 the Great Western opened in all some 180 miles of new track, constructed at heavy expense, with a view to "cutting off the corners" of Brunel's main lines, and—especially in the case of the Westbury and Bicester routes—to compete more effectively with other companies having shorter routes. The chief of these "cut-offs" (Fig. 6), were as follows:

Date of Opening.	"Cut-off" Line.			Shortening the Distance from London		Length of new Line.
	From	To	Via	To	By	
					Miles.	Miles.
1901	Patney	Westbury	Lavington	Weymouth	14¼	15½
1903	Wootton Bassett	Patchway & Filton	Badminton	South Wales Bristol	11¼ ¾	31
1906	Old Oak Junction	Ashendon Junction	High Wycombe	High Wycombe and Aylesbury	7½	*40¼
1906	Castle Cary	Cogload Junction	Somerton	West of England	†20	24½
1908	Tyseley	Cheltenham	Stratford-on-Avon	W. of England (from Midlands)	42	51¾
1910	Ashendon Junction	Aynho Jct.	Bicester	Birmingham and North	§18½	18¼

The effect of the opening of the Westbury route to the West of England was that the Great Western won back from the London and South Western all the traffic from London to Exeter and Plymouth that had been lost as a result of the South Western accelerations of service in the early years of the present century, when

* 34 miles Northolt Junction to Ashendon Junction constructed jointly with Great Central Railway.
† In conjunction with Patney Westbury cut-off.
§ In conjunction with Old Oak-Ashendon Junction line.

Pl. 13 C. 32

The Melide causeway across the Lake of Lugano, St. Gotthard Rly., Switzerland

C 31.

The [illegible] main line (metre gauge) in the upper Rhine valley, near Rhazuns, Switzerland (p. 40).

the L. & S.W.R. had a route to Exeter 22½ miles shorter than that of the G.W.R. Similarly the opening of the Bicester route to the North has enabled the Great Western to compete on level terms with the L.M.S. Railway for the custom between London and Birmingham, Wolverhampton, Shrewsbury and elsewhere. The G.W. line from London to Birmingham is now 110½ miles in length, as against the 113 miles of the L.M.S., and although the Great Western

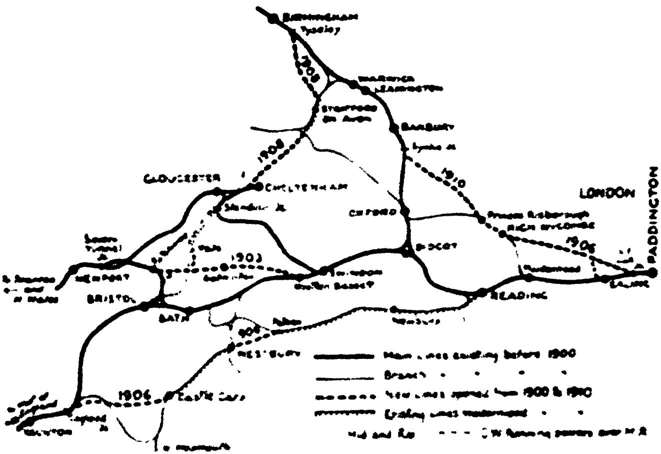


FIG. 6.—Map showing "Cut-off" Lines opened by Great Western Railway, 1900-1910

advantage in distance is more than offset by greater severity of gradients, both railways run a liberal service of two-hour trains between the two cities, including, in the majority of instances, intermediate stops at Coventry or Leamington.

Some of the heaviest grading in Britain is found on lines which skirt the sea-coast. The engineer's problem in this case consists in crossing the various lateral river valleys which intersect his path. The Great Eastern main

line of the L.N.E.R. is a case in point. Although running through the nominal flatness of the Eastern Counties, the Colchester main line of the old G.E.R. is a constant succession of heavy switchback gradients, and this, with the added hindrance of sharp curves through the chief stations, such as Stratford, Chelmsford, Colchester, Ipswich and for several miles through the outskirts of Norwich, as well as at Woodbridge and Beccles on the Yarmouth line, is ample explanation of the comparative slowness of East Anglian journeys. In consideration of these difficulties, and of the weight of the trains, such timings as the 82 minutes of the down Continental boat express trains over the 69 miles from Liverpool Street to Parkeston Quay, or the summer 2 hrs. 27 min. for the non stop journey of 121¾ miles from Yarmouth to London, entail some extremely hard work on locomotives of but moderate dimensions. On the latter run the engines have to lift their trains up adverse gradients to a total extent of no less than 1,660 ft. in the course of the journey.

The Great Western has a similar problem west of Newton Abbot, on the main line to Cornwall. Greater contrasts of grading than those which exist between Paddington and Plymouth could hardly be found in any other stretch of line of just over 200 miles in length. For 36 miles, from Paddington to Reading, Brunel's perfectly level line is followed. The next 61½ miles are divided between a long rise to Savernake and a fall from there to Westbury, with only a few miles steeper than 1 in 200 at any point. But there are substantially heavier grades between Westbury and Exeter, especially the 5 miles falling past Bruton, west of Brewham Summit, inclined mostly at 1 in 81 to 1 in 98, and the well-known Wellington bank, beyond Taunton, which rises steeply for 3½ miles, chiefly at 1 in 81 to 1 in 90.

Beyond Newton Abbot, however, the line is carried on the southern slopes of Dartmoor, near the sea-coast, and the gradients needed to cross the lateral river-valleys are exceedingly steep. For 2 miles up to Dainton Summit the line steepens from 1 in 57 to 1 in 47, with one brief strip actually at 1 in 36! The first mile of the subsequent descent to the valley of the Dart at Totnes is but little flatter than 1 in 40. Then follows the formidable climb to Brent, beginning with a couple of miles at 1 in 51, succeeded by 1½ miles at 1 in 90 and ½-mile at 1 in 125. After crossing a kind of "table-land," the line drops suddenly down from Hemerdon Signal-box to Plympton, for 2¼ miles averaging in inclination 1 in 42 continuously. Hemerdon bank is the terror of drivers of up trains as it comes but 4 miles after the Plymouth start, and there is little chance of getting a "run" at it; in the autumn, too, the rails are made greasy by the falling leaves of the trees which fringe both sides of the railway at this point.

Various proposals have been made to ease these excessive gradients, but the traffic carried over the line has not been considered sufficient to warrant the heavy expense of making the necessary deviations. Meanwhile even the new "King" class locomotives, which are rated as capable of hauling 525-ton express trains out of Paddington, are not permitted to haul more than 10 of the 70-ft. coaches between Newton Abbot and Plymouth, totalling in weight, with passengers and luggage, about 380 tons; engines of less power are more severely limited. The maximum composition of the famous "Cornish Riviera Express" from London, which detaches in succession slip portions at Westbury and Taunton, and a through coach for Kingsbridge at Exeter, is nicely proportioned to the progressive increase in the severity of the grading; the full weight of the train is round about 525 tons to Westbury,

450 tons to Taunton, 380 tons to Exeter, and 310 tons over the final stretch to Plymouth. It is significant of the difficulty of this final section, too, that, whereas the booked speed of the "Limited" is 60.2 m.p.h. from Paddington to Exeter, it has to be brought down to 44.6 m.p.h. from there to the Plymouth stop.

In other countries the problem entailed by the working of some of the earlier railways has occasionally become so acute as to make it imperative for the engineers to seek fresh locations. In undeveloped lands the craving for railway communication, after its vast importance had been realized, was so insistent that the lines had to be laid with the utmost haste. Money was scarce, and engineering work of any great magnitude was out of the question. If obstructions lay in the way of the railway, the engineers carried their lines round them or over them, with little regard either to distance or to gradients. In later years, however, the difficulty, as well as the cost, of working these lines, with the constant increase of traffic, became so formidable that alterations of route were a vital necessity. In some cases competing railways, laid at later dates and more carefully engineered, increased the urgency of the matter.

The main line of the Canadian Pacific Railway through the mountain ranges of Western Canada affords an interesting example of how an altered location of line has greatly simplified the working of one of the earliest of the Trans-continental railways of America. In its journey westwards from Calgary to Vancouver, the path of the Canadian Pacific was barred by the parallel ranges of the Rockies and the Selkirks, with the deep gorge of the Columbia River between. The line was carried through the Rockies by way of the Kicking Horse Pass, 5,329 ft. above the sea; then followed a drop of 952 ft. in no more than 4 miles,

involving for 3 miles continuously a gradient of 1 in 23. On the eastbound journey the working of one freight train of 710 tons up the " Big Hill " required the use of four 154-ton locomotives. The deviation illustrated in plan in Fig. 7 now enables two of the same locomotives to work 980 tons of freight from Field up to Hector, the maximum gradient having been reduced to 1 in 45. Two spiral tunnels were necessary, 3,255 and 2,922 ft. in length respectively, with the line doubling back on itself between them. The length of journey has been increased by 4 miles, but this is more than compensated for by the reduction in the number of locomotives operating the division.

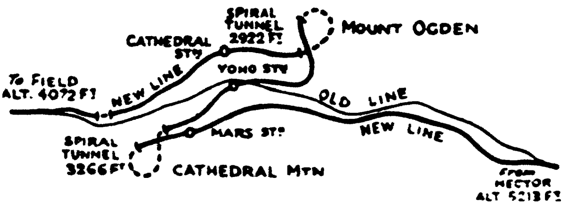


FIG. 7.—Deviation of the Canadian Pacific Railway in the Kicking Horse Pass

From Golden, at the bottom of the Columbia Valley, the line next climbed to the summit of Rogers Pass in the Selkirks, 4,309 ft. above the sea, which involved a rise of 1,768 ft. in 67 miles, followed by a drop of 2,857 ft. in the next 22 miles beyond the pass. Here a tunnel location replaced the route over the pass, and in this case reduced the length of route by 4½ miles, and the summit level by 552 ft. By easing the grade from 13½ miles at 1 in 45 to but a single mile at that grade, the deviation released a large force of pusher engines, snow-ploughs and other equipment, which until then had carried on a busy existence in the Rogers Pass, and the expenditure of so large a sum

as £1,250,000 on this one deviation alone was justified. The Connaught Tunnel (Fig. 8 and Plate 11), under Mount Macdonald, is 5 miles long, and was pierced in just over two years.

The Continent of America can furnish many other instances of radical improvement of railway routes. The Delaware, Lackawanna and Western Railway, for instance, spent £2,000,000 in a re-alignment of their route between Hopatcong Junction and Delaware Gap; a distance of 39½ miles separated these two points, sharply curved and as severely graded in parts as 1 in 88. The new location was designed to reduce freight train timings by 60 minutes

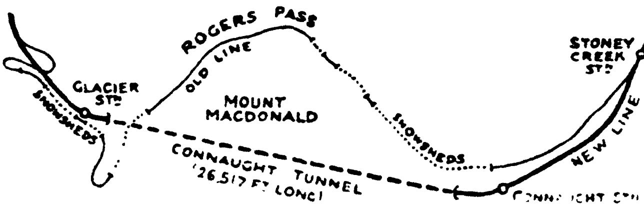


FIG. 8.—Connaught Tunnel Location Canadian Pacific Railway.

and passenger timings by 20 minutes—no inconsiderable amount in view of the competition of neighbouring and better-planned lines. Earthworks of vast extent were undertaken, one—the Pequest "Fill," 110 ft. high at the maximum—alone absorbing 6,600,000 cub. yards of spoil. So much dynamite was required for blasting purposes that a temporary explosive factory was erected on the spot. Viaducts of immense size included one over the Delaware River, 1,450 ft. long, having five spans of 150 ft., and two of 120 ft.; the rails are 115 ft. at the maximum above the floor of the valley.

One of the most striking of all the American "cut-off"

P. 15. D 30.

Crossing the Great Salt Lake, Southern Pacific Rly., U.S.A.

P. 16 *D* 37.

Three Levels of the St. Gotthard Railway, near Giornico, Switzerland (p. 40)

The entrance to Piano Tondo Tunnel is in left foreground, and the exit from Travi Tunnel is adjacent to the bridge over the River Ticino in right background

lines is that which the Southern Pacific Railway has thrown across the Great Salt Lake of Utah. The original main line from Omaha to San Francisco was carried round the north side of the lake, the location between Lucin and Ogden taking the track over heavy grades, as steep in places as 1 in 60 for a considerable distance, trains having to be lifted in all 1,515 ft. up the ascents to Promontory and Ombey. The line across the 31½ miles' width of the lake cut the distance between these points from 147½ to 103 miles, and substituted a perfectly straight and level route (Plate 15) for the previous ascents. Trainloads of rock and soil were excavated from the mountains on both sides of the lake, and were run out in both directions until a solid bed totalling all but 20 miles long had been extended towards the centre. Here the water was 30 ft. deep, and recourse was had to piling, a total of 38,256 trees of between 100 and 150 ft. in length, transported from the forests of Louisiana, Texas, Oregon and California, being needed before the 12 miles of trestle viaduct were complete. The St. Gotthard Railway of Switzerland is carried similarly across the Lake of Lugano on a causeway which was tipped on to an under-water glacial moraine near Melide (Plate 13).

Of all the countries in the world, it is probably diminutive Switzerland in which the *terrain* has given the greatest difficulty to the railway promoter, and where the art of railway planning, in consequence, has reached the highest stage of development. Centrally situated in Europe, Switzerland affords passage to some of the most important trans-European railway routes, which have therefore to pass through the mountain mass of the Alps. Of necessity the river valleys are followed by these lines, but it has been necessary also to employ many long tunnels, in order to carry these lines through from the valleys on one side of the Alpine watershed to those on the other.

The Simplon Tunnel, 12½ miles in length, is the longest railway tunnel in the world (apart from the London Tube tunnels); the St. Gotthard, 9¼ miles; the Lötschberg, 9 miles; the Ricken, 5¼ miles; and the Hauenstein, 5 miles, are other remarkable examples within Swiss territory; the Mont Cenis Tunnel, 8 miles long, in the Southern Alps between France and Italy, and the Austrian Arlberg Tunnel, 6¼ miles long, are further well-known trans-Alpine tunnels. Italy will shortly have a rival to the Simplon Tunnel in the 11½-mile bore which is at present being carried through the Apennine range to shorten the main line route between Florence and Bologna; this is expected to be completed in 1929. Tunnels, however, are dealt with at greater length in Chapter IV.

Even in the valley approaches to certain of these Swiss tunnels, it is with the greatest difficulty that the engineers succeeded in keeping their grading down to any figure reasonably capable of operation. The St. Gotthard and the Lötschberg routes probably have between them the most astonishing of the engineering locations seen on the Swiss main lines. In order to overcome the abrupt rise in the floor of the Kander valley between Frutigen and Kandersteg, without exceeding a maximum inclination of 1 in 37, the railway is doubled back on itself for fully 2 miles opposite Mittholz, the three levels of the line being carried on the eastern side of the valley, one above the other. One of the two semi-circular bends at both ends of the loop is made by means of a spiral tunnel bored in the mountainside, just over a mile long. After threading the Lötschberg Tunnel, and descending the Lötschental for 4 miles, the line turns south-eastwards, and suddenly appears high up on the north side of the Rhone Valley at Hothen, 1,312 ft. above the valley floor. From here it gradually descends for 12½ miles to join the main Simplon

route, which has been ascending the opposite side of the valley, at Brigue. Amongst the bold viaducts carried across various lateral valleys joining the Rhone is the Bietschtal Bridge, 255 ft. high. The cost of this 46-mile route, including the Lötschberg Tunnel, was £3,320,000.

Spiral planning is seen to even greater effect on the St. Gotthard route, as shown in Fig. 9. In ascending the valley of the Reuss, from Fluelen, on the Lake of Lucerne, to Göschenen, at the mouth of the St. Gotthard Tunnel, the railway is carried, at one point, through the completely

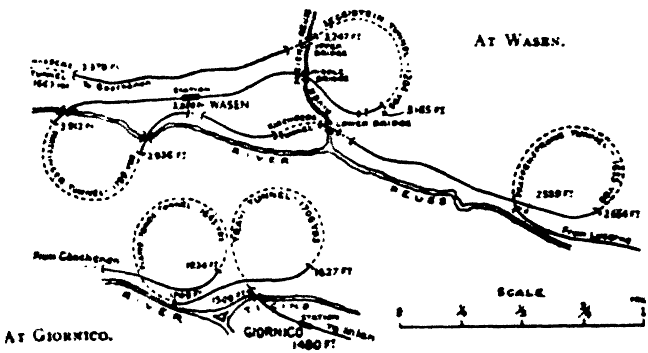


Fig. 9.—Spiral Planning on the St. Gotthard Railway.

spiral Pfaffensprung Tunnel, 1,635 yards long, and immediately afterwards makes an immense double loop opposite the village of Wasen, whereby the level of the line is raised by 400 ft. without any increase in the average gradient of 1 in 38½ to 1 in 40, which extends for some 18 miles on end, and lifts the track a total of 2,100 ft. The crest of the Alpine watershed is then threaded by means of the St. Gotthard Tunnel, and this brings the railway out into the valley of the Ticino. Wonderful planning

follows in this valley, in order that the fall of the railway may keep pace with the rapid fall of the valley floor. In the 13 miles between Rodi-Fiesso and Giornico there are four completely spiral tunnels, two of which—the Piano-Tondo and Travi Tunnels, respectively 1,643 and 1,706 feet long—are immediately adjacent to each other. In the first the line falls 115 ft. and in the second 118 ft.; the entrance to Piano-Tondo is high up the mountainside above the exit from Travi Tunnel (Fig. 9 and Plate 16), the difference in altitude of entrance and exit being 315 ft. In the 140 miles of the St. Gotthard line between Lucerne and Chiasso there are no less than 80 tunnels, all bored through solid rock and aggregating in length 28½ miles, with 324 bridges of over 32 ft. span, many of which are of considerable size, such as the Kerstelenbach Viaduct at Amsteg, 440 ft. long and 178 ft. above the river bed. The total cost of the line was £18,500,000.

Some feats of engineering more amazing still, if it were possible, are found on the narrow-gauge lines in the south-east of Switzerland. The Canton of the Grisons, mountainous throughout its large area, and broken up into some 150 valleys, many of which are the wildest of gorges, is sufficient, one would imagine, to daunt even the boldest railway prospector. Typical views of the country traversed appear in Plates 14 and 17. When the first section of the metre-gauge Rhaetian Railways had been opened from Coire—capital of the canton and terminus of the standard-gauge Swiss Federal lines—to Thusis, any further extension of the line appeared impossible. The Rhine here emerges from the gloomy recesses of the Via Mala—a profound chasm with sheer walls some 1,600 ft. high—and its tributary, the Albula, from the equally forbidding Schyn ravine. Passengers therefore transferred at Thusis into horse-drawn *diligences* for the remainder of the journey over the Albula

or the Julier passes to the increasingly popular resorts of the Engadine.

In face of active discouragement, however, the German engineer Hennings asserted that, given the money, he would connect Thusis with the Engadine by rail. In the brief space of six years, between 1898 and 1904, the line was completed through from Thusis to St. Moritz, a distance of 38½ miles, at the moderate cost of one million sterling. This was inclusive of rolling stock ; apart from the 3⅝-mile Albula Tunnel, which alone cost £282,800, the cost of the line itself was only £4,450 per mile. Yet there are 38 tunnels in addition to the Albula Tunnel, and bridges and viaducts in large numbers, some of them—such as the famous Solis Bridge, spanning a deep chasm at a height of 292 ft. above the river, and the Landwasser Viaduct, springing on a sharp curve out of the face of a sheer precipice, 213 ft. above the water level—of exceptional size. These structures are referred to in more detail in Chapter IV.

But the most noteworthy section is that connecting the watersheds of the Rhine and the Inn (a tributary of the Danube), between Filisur and Bevers, in the Engadine. The maximum grade of 1 in 40 previously employed now steepens to 1 in 29, but even this is far from sufficient to raise the line 3,500 ft. in the brief space of 8 miles. Actually the railway travels nearly 14 miles to accomplish the ascent ; between Bergün and Preda, in particular, the track has to be carried over a circuitous location 7¾ miles long to cover a distance of 3½ miles as the crow flies. The location here is bewildering ; no adequate description in words can be given, but the plan reproduced on the next page (Fig. 10) should help to make matters more clear. Obviously the use of so narrow a gauge as one metre, and the sharp curvature thereby rendered possible—generally kept at a minimum of 395 ft., but occasionally

falling as low as 328 ft.—gives the engineer a good deal more freedom in turning and twisting his line about, to make the best use possible of the footholds afforded by the flanks of the mountain valleys, than he would enjoy with a standard-gauge main line. At the summit of the Albula Tunnel the railway is 5,998 ft. above the sea.

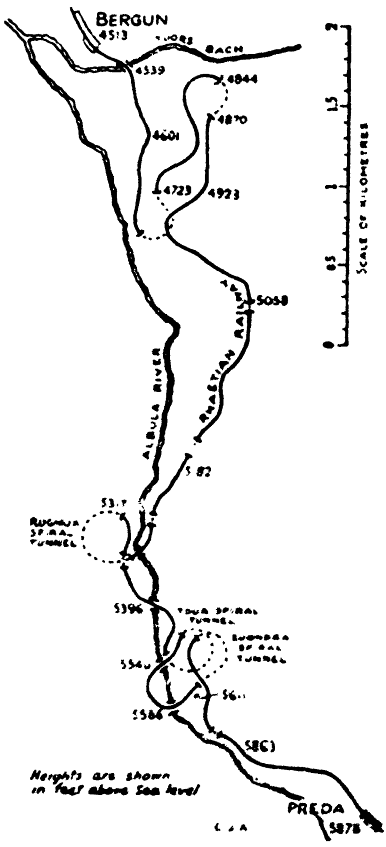


FIG. 10.—The Tortuous Location of the Rhaetian Railway between Bergun and Preda.

On the continuation Bernina Railway, connecting the Rhaetian system with the Italian line which comes up the Val Tellina from Lake Como, although the metre gauge is still employed, the maximum steepness of gradient is increased to the astonishing figure of 1 in 14, which is used over long stretches of line. This is probably the steepest adhesion line of its length in the world; the use of such gradients, of course, renders necessary a rigid limitation of the loads hauled by unassisted electric engines or motor

coaches. The planning of the line calls for no particular comment until the Bernina Pass has been crossed, at an altitude of 7,400 ft., when the engineers were faced with the prodigious descent to the Poschiavo Valley, 4,000 feet below them. From Alp Grüm one can look straight down an almost precipitous slope to the next station—Cavaglia—in a kind of glacial basin 1,300 ft. below ; and the railway then passes through a narrow gorge out on to another similar slope, reaching the town of Poschiavo, yet another 2,240 ft. below, by eleven reverse bends. By comparison with the 1 in 14 of the electrically-operated Bernina Railway, the steepest adhesion line worked with steam locomotives is probably that between Halberstadt and Blankenburg, in the Harz Mountains of Germany, which has a lengthy continuous stretch of line inclined at 1 in 16½.

Steeper ascents than these can only be accomplished by the assistance of the "rack." In rack-and-pinion propulsion, the use of the ordinary locomotive driving wheels is abandoned in favour of a pinion-wheel whose teeth engage in the teeth of a steel rack, strongly secured in the centre of the track, between the two running rails. This form of railway operation is avoided as far as possible, because of the severe limitation that it imposes on the speed of the trains, but on exceptional ascents the use of the rack is indispensable. It enables the steepness of inclination to be increased to a maximum of about 1 in 2, which is the ruling gradient, for example, on the railway which makes the ascent from Alpnachstad, on the Lake of Lucerne, to the summit of Pilatus. This line ascends 5,347 ft. in the course of a journey of 3 miles, which is made by a combined 32-seater steam engine and coach in 75 minutes. There are many similar "funiculars" in Switzerland, of which the illustration of the Martigny-Châtelard line is typical (Plate 18), and it is the proud boast of the Swiss

that no fatal accident has ever occurred to a passenger using any one of them, such is the completeness of the safety precautions laid down by the Swiss Government for their working.

On certain through mountain lines, the use of the rack is confined to the steepest lengths, and combined "rack-and-adhesion" locomotives are employed, the ordinary driving wheels being employed on the adhesion sections, and the pinion gear, to which the driver can change at will, on the rack ascents and descents. The Brünig line, connecting Lucerne with Meiringen and the Bernese Oberland is one of these; another is the lately-completed Furka-Oberalp Railway, which crosses the Oberalp and the Furka Passes in succession on the way from the Rhine Valley to the Rhone Valley. In the course of a journey of 27 miles from Disentis to Gletsch, this line rises from an altitude of 3,760 ft. at Disentis to 6,720 ft. on the Oberalp; from there it drops to 4,735 ft. at Andermatt, where the path of the St. Gotthard Tunnel, 1,000 ft. below, is crossed; then comes the ascent almost to the summit of the Furka, the crest of which is, however, pierced by a tunnel just over a mile long, at an altitude of 7,120 ft.; after which there is the descent to Gletsch, in full view of the Rhone Glacier, to a level of 5,710 ft. This section is only operated in summer, but the continuation down the Rhone Valley for 28½ miles to Brigue, 2,215 ft. above the sea, on the main Simplon route of the Swiss Federal Railways, is open all the year round.

The highest of European railway altitudes is attained by the line which has been carried to within 2,000 ft. of the summit of the Jungfrau, most famous of all the giants of the Bernese Oberland. Access is gained to the Jungfrau Railway by the rack lines of the Bernese Oberland Railway, the commencement of the former being at Kleine Scheidegg.

/ . 18.

6,770 ft. above the sea. From there the Jungfrau Railway makes direct, at an inclination of 1 in 4, for the north face of the pyramidal and precipitous Eiger. It was impossible to carry the line on the face of the precipice, and the face of the Eiger is therefore entered, at an altitude of about 8,000 ft., after which the line climbs inside the mountain for 4 miles, skirting the slope of the Eiger and later of the Mönch until it reaches the Jungfraujoch terminus, at the summit of the pass between the Mönch and the Jungfrau, 11,342 ft. above the sea. At this and the intermediate stations of Eigerwand and Eismeer lateral tunnels have been driven to the face of mountain, in order to enable the passengers to see the incomparable views. Serious difficulties were experienced in completing this line, whose total length of 5¾ miles occupied 16 years—from 1896 to 1912—in construction, and swallowed up nearly half a million sterling in money.

Still steeper ascents than those mentioned have been conquered by the use of rope haulage, the weight of the descending car being used to assist the haulage of the ascending car. Lines of this description, which are familiar at many English coast resorts, allow of the use of gradients almost as steep as 1 in 1. The steepest of the Swiss cable railways is that at Ambri-Piotta, in the Canton of the Ticino, which mounts 2,145 ft. in the compass of 7/8-mile, with a gradient whose maximum severity is 87.8 per cent. The fact that one continuous cable must be used restricts the maximum length of railways worked in this way; where the length exceeds one mile, the line is usually built in two or more sections, with a change or changes of carriage intermediately.

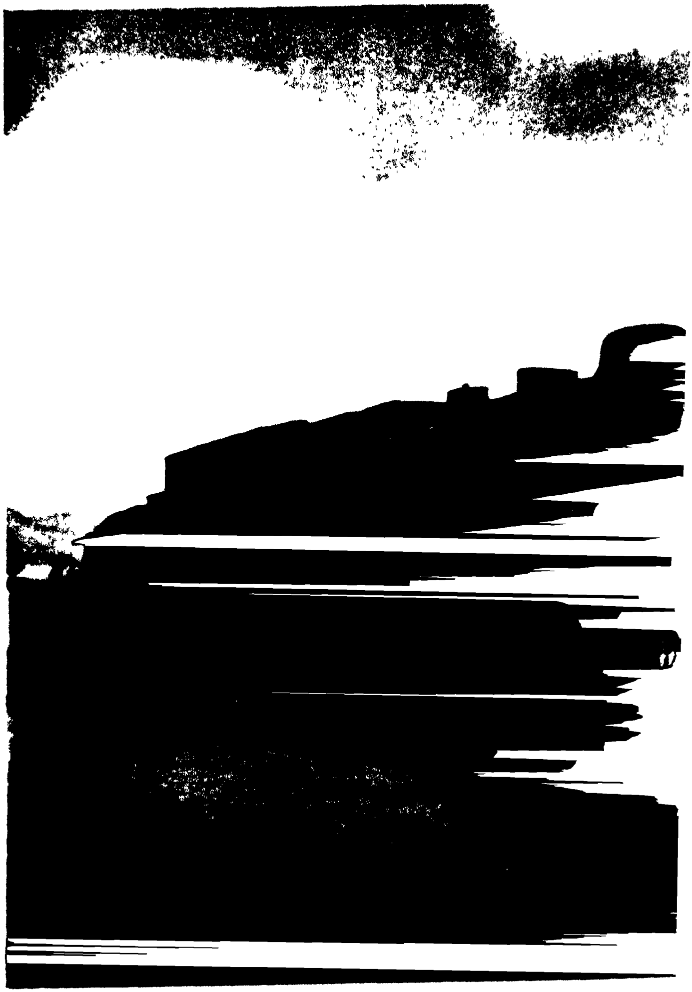
There is one further description of mountain railway deserving of mention, though as it is unprovided with rails, such a title as "railway" is strictly a misnomer.

CHAPTER III

The Choice of Gauge

EXACTLY how the gauge of our railways came to be fixed at the curious figure of 4 ft. 8½ in. is a matter in which our railway historians are not in agreement. It is said that the early railway-makers decided that they could not do better than copy the distance between the centres of the parallel lines of stone blocks used by the Romans in making their roads, traces of which still exist in Tyneside. Others claim that George Stephenson measured the distance between the wheels of his farm cart, and adopted the same dimensions between the wheels of his early locomotives.

Most probable of all the reasons, however, is this. The earliest wagon "plate-ways" consisted of iron "angles," set up back to back, at a distance roughly 5 ft. apart; the tread of the wheels ran on the flat of the angles, and the other leg of each angle, upstanding, by contact with the inside of the wheels, kept them running truly in line. When rails first came into use, in place of angles, and flanged wheels with them, the flanges of the wheels ran on the *outside* of the rails, instead of between them; the gauge of the tracks, maintained at 5 ft., therefore comprised the distance between the rails, *plus* the width of two rail-heads. Later on it was decided that it would be better for the wheel-flanges to run on the inside of the rails than on the outside, and the gauge then was reduced automatically by the deduction of the two rail-heads. At that time the rails were 1¾ in. wide across the head,



and 3½ in. deducted from 5 ft. left our present standard gauge of 4 ft. 8½ in.

The standard, once settled, was difficult to alter. As soon as large numbers of locomotives, carriages and wagons were running on the 4 ft. 8½ in. gauge, any alteration of the gauge would have involved, not only the moving of the rails, but extensive alterations to rolling stock as well. As Great Britain had pioneered in the matter of railway construction, and many of the earliest locomotives in other countries were of British origin, the gauge of 4 ft. 8½ in. thus became standardized in many parts of the world, including the whole of the great Continent of North America. The railway gauge of Europe, also, has become fixed at 1.45 metres, of which the British equivalent is 4 ft. 9 in., and this is sufficiently near to the British gauge to allow of the through running of vehicles, *via* the Harwich-Zeebrugge train ferry, from English towns to destinations in almost any Continental country, and *vice versa.*

European countries which have widened their gauge are Spain and Portugal, with a gauge of 5 ft. 5⅝ in., and Russia, with 5 ft. Through train running between these countries and the rest of Europe is, of course, impossible, and passengers have to change trains at the various frontier stations, while all the freight requires transhipment from the wagons of the one gauge to those of the other. The only other extensive variation of the standard in Europe, singularly enough, is in Ireland, whose main lines, a typical view of which appears in Plate 12, have been laid on a standard gauge of 5 ft. 3 in. Special rolling-stock has, therefore, to be built by the British L.M.S. Railway for the working of its lines in Ireland. In India the even wider gauge of 5 ft. 6 in. used on the main lines permits of the employment of locomotives and rolling stock of great size (Plate 22).

At one time England was threatened with a development

in the matter of railway gauge which would have left her in much the same unfortunate position as that in which the Continent of Australia finds itself to-day. Brunel, the famous engineer of the Great Western Railway, to whose methods of railway planning reference has already been made, came to the momentous decision to employ a gauge of 7 ft. instead of the standard of 4 ft. 8½ in. It was a daring policy, partly conceived with the idea of keeping all rivals out of the West Country, but it was not sufficiently far-sighted. In the "Battle of the Gauges" which ensued, so called because of the attempts made by the protagonists of both broad and narrow gauges to prove that each was in the right, while the other was in the wrong, Gooch, the Locomotive Superintendent of the Great Western Railway at Swindon, built locomotives whose power and speed capacity were far in advance of the standards then prevailing on other lines. The carrying capacity of Great Western coaches, in consequence of their extra width, was also greater, in proportion to their weight, than that of other companies' carriages, and the smoothness of riding over the "Broad Gauge," as it was called, was proverbial. Had the advocates of the Broad Gauge prevailed, the whole of our ideas in regard to rolling stock design and construction might have been altered. It would have been possible to mount boilers of far larger diameter on our locomotives, clear of the driving wheels, and to increase the carrying capacity of coaches and wagons in proportion to their length, thereby reducing working costs, although, on the other hand, the necessarily increased radius of the sharper curves would have affected adversely the costs of line construction.

But Brunel failed to foresee that the Great Western Railway could not be kept, as it were, in a "water-tight

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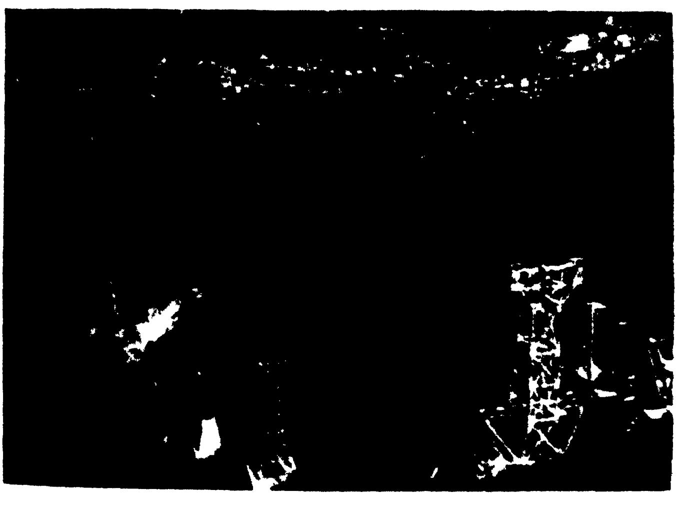


other British line. It was impossible to run a Great Western wagon or coach through on to any other system. Construction on the 4 ft. 8½ in. gauge had proceeded so far in all parts of the country that to widen the narrow to the broad gauge was unthinkable ; even if the managements of the various other railways had agreed as to the desirability of so doing, the cost would have been fabulous. So it was inevitable, in the end, that Brunel's broad gauge of 7 ft. should be contracted to the standard figure of 4 ft. 8½ in. It is certainly cheaper to contract than to widen ; the work in general is confined to shifting one rail of each track and making the necessary alterations to rolling stock, as the various permanent structures along the line—bridges, tunnels, station platforms, and so on—are not greatly affected.

Before the actual change-over took place—many years before, in some cases—it had become necessary to lay a "mixed gauge" (Plate 21) along various of the Great Western main lines ; that is to say, a third running rail was laid to each track, making it possible to run either 4 ft. 8½ in. or 7 ft. gauge vehicles. The last operation was that of removing the broad gauge altogether. Converting the branch lines was a simple enough matter, but the conversion of the main lines involved some of the most remarkable feats of railway engineering organization that this country has ever seen. Enormous labour forces were got together ; short sections of line were tackled first, in order that experience might be gained ; 5,000 men then got to work in 1872 on the Gloucester and Milford Haven section, which, with branches, totalled 500 miles of track, and so far as the main line was concerned, completed the down line in a single week, and the up line in the week following.

Last of all, after various important branches, came the

170 miles from Exeter to Plymouth, the gauge of which was actually changed in two days—May 21st and 22nd, 1892. Prior to this every broad gauge engine and coach had been worked east of Exeter, and on May 20th the "Cornishman" had left Paddington at 10.15 a.m., on its last melancholy journey as a broad gauge express. It is difficult to estimate to the full what Brunel's error of judgment cost the Great Western Railway; when the decision to change the gauge was first reached, in 1869, apart from the fact that there were 1,500 miles of broad gauge track in existence, all to be converted, there were 700 broad gauge engines, and a proportionate quantity of passenger and goods rolling stock, much of which would have no narrow-gauge value. One has a far greater admiration for the foresight of George Stephenson, who, when planning railways as far apart as the counties of Durham, Lancashire, Leicestershire and Kent said: "I tell you, they must all be 4 feet 8½ inches. Make them of the same width; though they may be a long way apart now, depend upon it they will be joined together some day." And joined together they now are.

We have an object lesson in the Australian Continent of the evils of failing to agree on any uniform policy in the matter of railway gauge. Each Australian State has settled its own standard. West Australia and Queensland, pioneering through the "bush" in what was largely undeveloped country, and having to do so as cheaply as possible, chose the 3ft. 6 in. gauge. Victoria and South Australia, to serve their thickly populated territories, decided on the generous figure of 5 ft. 3 in.; striking Australian pictures, showing the development of rolling stock possible on the 5 ft. 3 in. gauge, appear in Plates 65 and 145. New South Wales alone was content with the world standard of 4 ft. 8½ in. So, at the frontier between each Australian State and the next, there is a "break" of

gauge, and apart from the inconvenience, the loss of time and needless expense involved in the transfer of all passengers and goods from one gauge to the other at the frontier stations is enormous.

The Federal Government has now decided on a standard gauge of 4 ft. 8½ in., and the important Trans-continental line from east to west, and also the partly-completed north to south line, have been constructed on the 4 ft. 8½ in. gauge. But whether the four States which have adopted gauges other than 4 ft. 8½ in. will ever face the problem of altering to the standard gauge is very doubtful; the cost would be colossal, as apart from the actual alterations of track and structures, vast quantities of engines, coaches and wagons would have no further use. It is interesting to remember that the little Dominion of New Zealand boldly faced this question years ago, and decided upon a standard gauge of 3 ft. 6 in., which now prevails over both North and South Islands. But the longer the move is delayed, so much the more difficult and costly does it become.

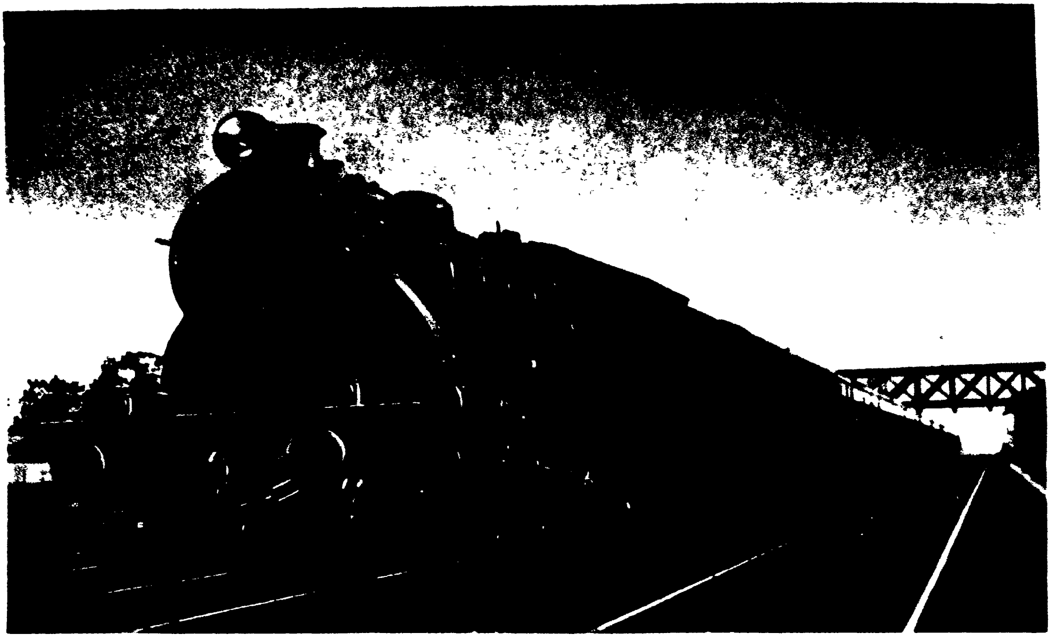
The railway gauges in general use are as follows:

Gauge.	*Countries.*
5 ft. 6 in.	India, the Argentine, Chile, Brazil.
5 ft. 5⅝ in.	Spain, Portugal.
5 ft. 3 in.	Ireland, South Australia, Victoria.
5 ft. 0 in.	Russia.
4 ft. 9 in. (1.45 metres)	Europe generally (except Great Britain, Ireland, Russia, Spain and Portugal).
4 ft. 8½ in.	Great Britain, United States, Canada, New South Wales, Egypt, China, Peru.
3 ft. 6 in.	South Africa, Western Australia, Queensland, New Zealand.
3 ft. 3⅜ in. (1.00 metre)	Smaller lines in Egypt and India; small independent lines in Europe and railways in the Colonies of European countries, etc.
2 ft. 6 in.	Chile (main lines now widened to metre gauge).
2 ft. 0 in.	Feeder lines in South Africa and elsewhere

From the table overleaf it will be seen that the railways fall into groups of three—main lines of 4 ft. 8½ in. gauge and upwards; lines of the closely similar 3 ft. 6 in. and metre gauges; and very narrow gauge lines of 2 ft. or thereabouts.

When account is taken of the remarkable achievements of the Union of South Africa on so modest a gauge as 3 ft. 6 in., it is difficult any longer to regard this as a "narrow" gauge. The latest Baldwin-built 4–8–2 and 4–6–2 express locomotives (Plate 26), built for working the "Union Limited" express trains between Cape Town and Johannesburg, weigh without their tenders 101½ and 90 tons, and with their tenders no less than 155 and 167 tons respectively in working order. Compare with this the latest "Flying Scotsman" 4–6–2 engines of our London and North Eastern Railway, whose 96 tons without and 152 tons with tenders represents the biggest weight of a passenger locomotive ever yet put on the British 4 ft. 8½ in. gauge, and the South African figures become the more arresting. For the working of freight traffic a far larger locomotive has been introduced recently, of the 2-10-2 type (Plate 24); this machine weighs no less than 118 tons in working order, and with a tender carrying 6,000 gallons of water and 14 tons of coal, 190½ tons in all. Among various experimental feats, this engine succeeded in starting a freight train of 1,800 tons on an up gradient of 1 in 100; and it is worthy of note, also, that despite the length of wheelbase, it is capable of traversing curves of no greater than 300 ft. radius. South African coaching and wagon stock, again, is just as wide as that in use in this country (Plates 23 and 26), the overhang on each side of the track being as much greater, in the case of the narrower gauge, as is represented by one-half the difference between 3 ft. 6 in. and 4 ft. 8½ in.

The first object of the railway-builder in laying a gauge



From ph...

Pl. 22

P. 51

The Punjab Mail, East Indian Rly. (5ft. 6in. Gauge)

Hauled by ... standard ...

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Interior of Restaurant Car, South African Rlys. (p. 54)

. . . . capacity on the 3ft 6in gauge.

that is narrower than normal is to cheapen the cost of his line. His idea is to take in less land than would be required by the standard gauge, to lay a lighter track, to build less costly bridges and structures, and to content himself with locomotives of a power, and coaches and wagons of a capacity proportionate to his needs. More important still, the use of a narrow gauge enables him to sharpen his curves, which in mountainous country is of great value, as he can in this way follow the contours of the hills closely (Plate 27), and avoid heavy earthworks or costly bridging and tunnelling. South Africa began in this way, but her railways have now grown so enormously in importance that standard gauge capacity is required on the narrow gauge tracks. So the permanent way of the South African lines has been brought up to broad gauge standards, with rails of 100 lb. per yard weight on the busy sections; bridges have been rebuilt and strengthened; and, as we have seen, engines of enormous size have been introduced. In the matter of speed, however, South Africa will always be limited by the narrowness of its railway gauge, and even on the best trains (Plate 129) a speed of 50 miles per hour is but rarely exceeded. The Dutch island of Java, by the way, has the reputation of running some of the fastest trains in the world on a gauge as narrow as this; the actual gauge in Java is 3 ft. 3⅜ in. (one metre), but over this trains are booked at start-to-stop speeds as high as 41.5 miles an hour, and frequently attain maximum speeds of 55 m.p.h.

What can be done on even narrower gauges than this we need not leave our island to see. Some of our narrow-gauge railways have quite undeservedly earned the nickname of "Toy" railways, whereas they are really quite serious concerns, being worked profitably and well. A number of the best-known of these lines—the Festiniog, the Rheidol

and other of the North Wales lines, and the Lynton and Barnstaple in Devon—have been laid to the uniform gauge of 1 ft. 11½ in. All the year round the Festiniog carries from the quarries at Blaenau Festiniog to the sea at Portmadoc a heavy traffic in slate. It has been carefully planned with an even gradient throughout its length, so that trains of slate may be worked down from the quarries to the coast by gravity alone, the engines hauling the empty wagons back to Festiniog again. As an illustration of the loads which may safely be carried on the 1 ft. 11½ in. gauge, the latest Great Western 2–6–2 tank engines used on the Vale of Rheidol Railway, in North Wales, from Aberystwith up to Devil's Bridge, have a total weight of 25 tons in running trim. But these engines are handsomely beaten by the latest 2–8–4 locomotives working the 2 ft. gauge railways of Gwalior, in India, which weigh no less than 38½ tons in working order.

One of the most remarkable of all the examples we have in this country of the carrying capacity of an exceedingly narrow gauge is the Ravenglass and Eskdale Railway, in south-west Cumberland. Originally laid as a mineral line to a gauge of 2 ft. 9 in., and proving, financially, a disastrous failure, the Eskdale Railway was converted, in 1916, to a gauge no wider than 15 inches; the idea was really to make it into a kind of super-"scenic" railway, working the trains with miniature express locomotives, as had often been done previously in exhibition grounds and marine parks at seaside resorts. After some years of experiment and improvement, this little railway—which, with some reason, claims to be the "smallest public railway in the world"—has now reached the happy position of paying its way. For passenger work the chief locomotives employed were exact scale models of full-sized tender engines, two "Pacific" engines, modelled on a scale of 3 in

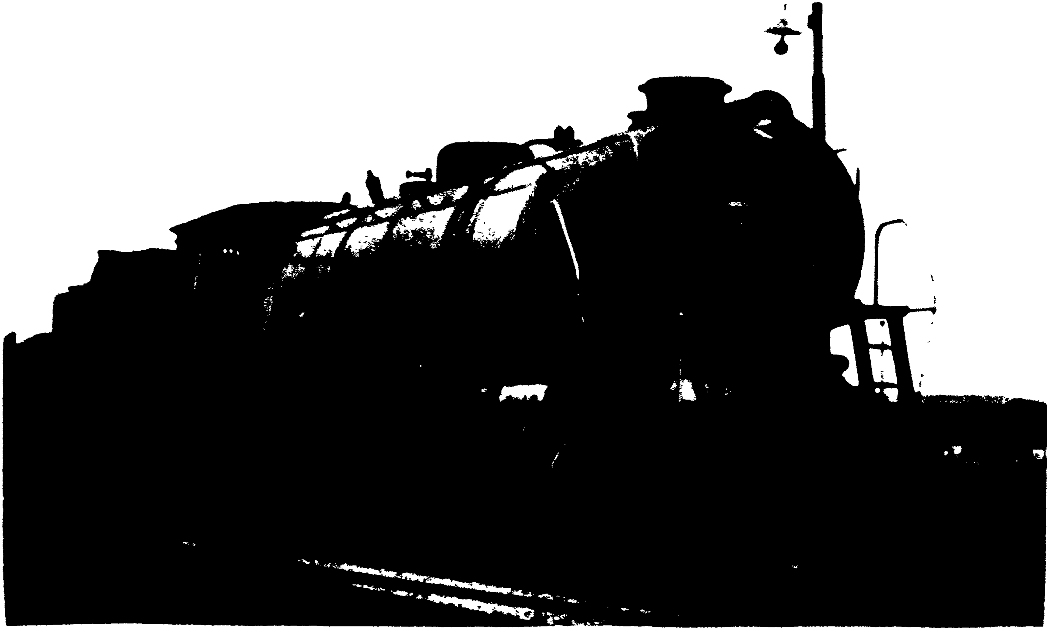
to the foot, and a 2–8–2 or "Mountain"-type engine, scaled at 4 in. to the foot, being in use. The two "Pacifics" have now been converted into one articulated locomotive resembling an engine of the "Garratt" type, and the 2-8-2 locomotive has been provided with a steam-driven tender in accordance with the Poultney patents; in this way two units are available of exceptional tractive power for so tiny a gauge, each capable, in fact, of handling trains of 200 passengers and upwards in the light open coaches that are used.

For working a heavy traffic in broken stone which passes over the railway, several powerful petrol tractors are in use, consisting of lorry engines which have been adapted for use over rails; one of these tractors can manage a load of 35 tons. For the stone traffic high capacity bogie hopper wagons have been devised, each holding 6 tons of broken stone, and weighing empty 2½ tons. With light passenger trains a "Ford" engine, fitted into a double-bogie chassis, has reached speeds of 36 m.p.h. on this narrow track with perfect safety and smoothness. These details are given as affording some indication of the capacity of the 15-inch gauge, which may be held to constitute the very narrowest limit on which a public railway can properly be operated. A characteristic view of a passenger train entering Irton Road Station of the Eskdale Railway appears in Plate 28.

In 1927 a considerably more ambitious 15-inch gauge railway was opened along the south coast of Kent, between Dungeness, New Romney, Dymchurch and Hythe. In this case a double line has been laid throughout, fully signalled, and four handsome stations have been erected at the places mentioned, two of which have "all-over" roofs and accommodation for handling a large volume of traffic. Passenger trains are run, at busy times, of from

17 to 20 vehicles, with seating accommodation for 130 to 160 people; the haulage is entrusted to five fine scale model locomotives of the 4-6-2 type (Plate 28), miniatures of the Gresley "Pacifics" of the L.N.E.R. (two of these engines are actually 3-cylinder models), and two larger "Mountain" or 4-8-2 type engines, of the same general lines externally, all with double bogie tenders. All these models are scaled out at 4 inches to the foot, which is slightly more than proportionate to the gauge scale of 3 in. to the foot, though the difference is barely evident externally. Each engine and tender weighs rather over 8 tons; maximum speeds attained are over 30 m.p.h. Little engineering of note was required, apart from one 50-ft span lattice-girder bridge over a stream, the flatness of the country traversed reducing construction to the simplest terms. It is some indication of the capacity of a 15-inch gauge line that this diminutive railway carried 75,000 passengers in the first month of its working.

There is another very important aspect of the gauge question which requires mention before this chapter is concluded. We are reminded of it whenever we see, at the exit from a railway goods yard, the strip of steel, curved into the shape of an arc, that is suspended over the track from an erection which is not unlike a gallows in appearance. This is called the "loading gauge," and its purpose is to show the men who have loaded out-going wagons whether or not the tops of their loads will clear the bridges and tunnels *en route*. The railway loading gauge at the same time represents the utmost limit to which locomotives and coaches may be built, in order that they may pass safely through the "construction gauge," which, in its turn, is the minimum limit to which structures may be erected, either above or at the side of the line, if they are not to foul the rolling stock.



P. 24

Maximum Locomotive Development on the 3ft. 6in. Gauge

[illegible]

4-4-2 ("Atlantic") Express Locomotive, Egyptian State Rlys. 113

This matter of construction gauge, unfortunately enough, is one in which our far-seeing railway pioneers did not see sufficiently far ahead. As we shall note later on, our locomotive designers of to-day are severely cramped in their designs of both locomotives and coaches, in view of the narrow limits through which both must pass. Even in the best conditions, 13 ft. 6 in. represents the outside limit of height above rail to which a British locomotive may be built, and 9 ft. to 9 ft. 6 in. is the maximum limit of width. The disposition of all the parts of some of our biggest modern locomotives, such as the "Pacifics" of the L.N.E.R., to keep within this minimum clearance, has been a marvel of ingenuity. At the same time, we have here the reason why the funnels, domes and other boiler mountings of our present-day locomotives have shrunk almost to vanishing point; the increase in the diameter of boilers has forced up their centre-lines until practically no more clearance is left on top. Some British routes are not fortunate enough to have even 13 ft. 6 in. headroom above tracks; and the modern tendency, therefore, is still further to reduce the height of the latest standard locomotives of our grouped railways, by as many inches as will permit them to run over all main line sections of the systems concerned.

We find almost every other country in the world in a happier position than ourselves in this matter of rolling stock construction limits. We have already seen how the South Africans are able to build bigger and heavier passenger locomotives than the biggest in Great Britain; this is explained by the fact that the South African construction gauge is both higher above rail and wider than our own. On the Continent of Europe locomotives and coaches can be built, in general, to a height of 14 ft. above rail, and to a width of 10 ft. 2 in.; for this reason, though English

rolling stock can be run over the railways of the Continent —and was, of course, so run very largely over the railways of France during the Great War—the converse is not possible. The wagons which are used for through running between Continental countries and England by the Harwich-Zeebrugge train-ferry were specially built for the purpose, to British clearances. When the Channel Tunnel idea was revived at the end of the war, the question of enlarging the British railway construction gauge, on the lines principally affected, was examined, but the cost was found to be so colossal as to put the proposal out of court altogether.

It is the American continent, however, which has profited the most by our experience. On the chief American railways it is possible to build to a maximum height of 16 ft. (Plate 19) above the rails, and to a width in proportion. As befits a country which claims to be the land of " big things," therefore, the American railways can certainly boast the largest locomotives, coaches and wagons in the world. As against a maximum engine and tender weight of 152 tons in this country, or the 178 tons of the L.N.E.R. " Garratt " type banking engine, engines and tenders have been built in the United States to a total weight of 400 tons, and with a tractive power proportionate to the increased size. Freight wagons with a capacity of 100 short tons each are not uncommon, and the Virginian Railways have gone one better with twelve-wheeled coal cars of 125 short tons (107 British tons) capacity. It is on record that a coal train with a gross weight of no less than 16,000 tons has been moved by one locomotive over the main line of the Virginian Railways, the chief problem entailed by this feat being not the actual haulage, singularly enough, but the problem of applying the brakes on a train of such immense length, when running downhill. In the westbound direction an engine of the same type has worked a train of

201 empty cars, weighing 4,573 tons and measuring in length over 1¼ miles, against the grade from the sea to the mining area.

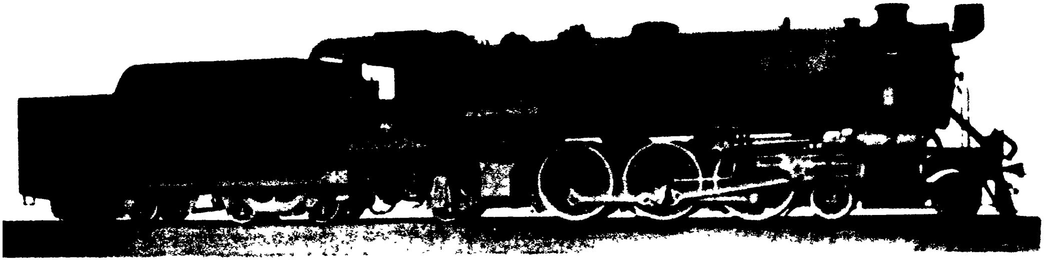
The chief points to remember in connection with railway gauges are, therefore, that while the cost of railway construction and equipment fall proportionately to the narrowing of the gauge, speed of transit and carrying capacity fall at the same time. Consequently narrow gauge lines, in general, are used only as "feeders" to main lines. But uniformity of gauge is, as far as reasonably possible, the ideal aimed at by the railway engineer.

CHAPTER IV

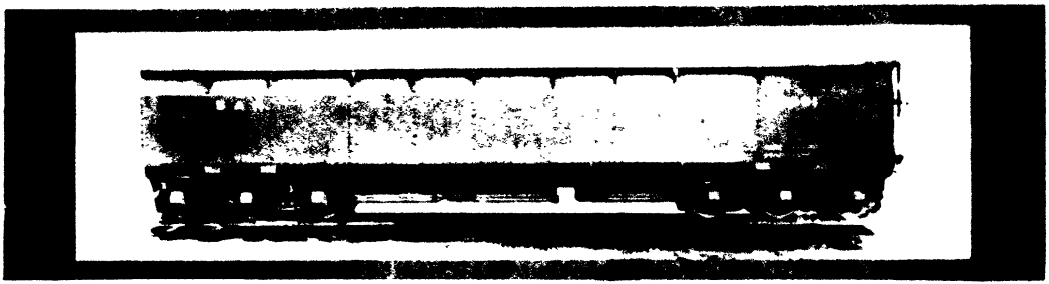
Bridging and Tunnelling

WHEN a decision has been reached as to the route to be followed by the railway, and the gauge over which its trains will work, the next matter for consideration is that of the engineering structures *en route*. As explained in Chapter II, the magnitude of these will be ruled largely by the amount of traffic which the promoters expect that the line will carry. A line which is likely to be run very profitably will justify more expense in construction than one which can offer but little in the way of revenue. A new route, shortening or improving the gradients of an existing route, will justify expenditure in some rough proportion to the saving that it is likely to effect in the cost of working the traffic. Herein you have the explanation of many of the monumental structures which have been completed from time to time in railway history.

The Severn Tunnel cost the Great Western Railway two millions sterling, for example, but with the Badminton route it has cut 25 miles off the previous journey to South Wales, as well as easing the gradients and curves, thereby rendering possible tremendous economies, both in time and in the cost of working the increasing passenger and mineral traffic to and from the industrial centres of Monmouth and Glamorgan, and the port of Fishguard. The Forth Bridge cost three millions, but with the Tay Bridge it has been the making of the East Coast route north of Edinburgh, prior to their construction effective through working up the



4-6-2 ("Pacific") Express Locomotive, used for working passenger trains across the Karoo (p. 56)



P. 20 F. 62

[illegible] Wagon [illegible]

Modern Rolling Stock, South African Rlys. (3ft. 6ins. gauge)

7 — E 63.

The windings of the main line of the South African Railways in the Hex River Pass (p. 55).

[illegible] railway construction.

East Coast of Scotland was impossible, because of the obstruction created by the widespreading waterways that the lines span. When such structures as these come into use, special measures have to be taken in order that a reasonable return may be obtained upon their capital cost. The Forth Bridge, for example, is an independent company, and an amount considerably more than proportionate to its actual length is credited to this company out of all the fares and rates that are levied over it. A similar system prevails in Switzerland, where the rate charged for travel is based, on the lines whose construction costs were heavy, not on the actual distance covered in kilometres, but on what is called the "effective" kilometrage. On any particularly costly lengths, therefore, the "effective" kilometre is a good deal shorter than the actual kilometre, and the fares are correspondingly high. But this is only reasonable.

The ordinary bridgework of the railway requires but brief consideration. A large majority of the bridges, both under and over the line, consist of single spans only, and are either brick arches, or small girder structures. "Plate" girders, built up from flat steel plates, and stiffened by steel angles, are used for the shorter spans, but as the length of span increases, more complicated forms of construction become necessary. The thin steel plate which forms the upright part of the main girder—known as the "web"—is replaced by a lattice-work of flat steel bars, the "plate" girder thus becoming a "lattice" girder. Of lattice girders there are many types, named according to their general appearance, such as the "bowstring," "hog-back" and other varieties. The most general of all lattice-girder types is the one with flat top and bottom flanges and sloping ends, such as the skew span, seen in course of erection at Hampton Court Junction, in Plate 29. It is, of course,

to lighten the weight of steelwork required that lattice construction is employed. Amongst the largest and finest lattice girder railway bridges in the country may be mentioned the £536,000 King Edward Bridge over the Tyne, and the £450,000 Queen Alexandra Bridge across the Wear, both constructed by the late North Eastern Railway. The former, with its two 300 ft. and one each 231 ft. and 191 ft. spans, carrying four tracks, absorbed 9,300 tons of steelwork and 465,000 cub. yards of granite, and the latter, which carries the railway on its upper deck and a road on the lower deck, and has a central span of no less than 330 ft., consumed 9,000 tons of steel. It is illustrated in Plate 30.

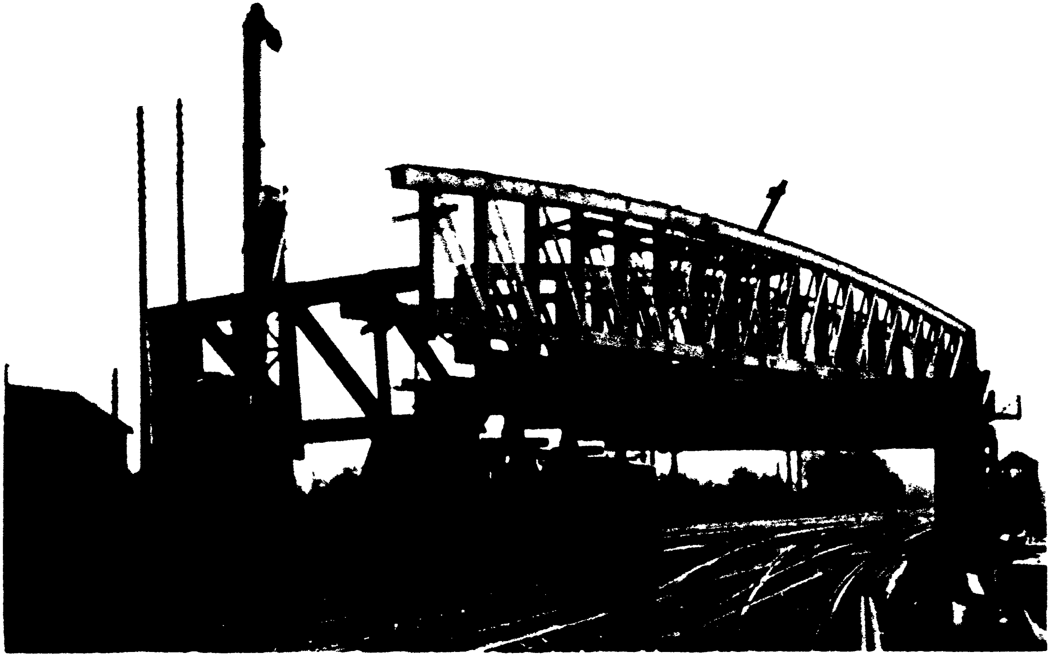
Bigger spans than these require special designs. They are almost invariably connected with the passage of railways across waterways; in fact, practically all the most remarkable bridges in the world are across water. The chief consideration in these cases is whether or not intermediate piers can be built, and this, in its turn, depends upon the depth of the water, and the nature of its bed. Needless to say, the location of the railway is brought to the water, if possible, at the point where the waterway is at its narrowest, or, alternatively, where the presence of islands in the channel offers the prospect of a firm support for central piers.

Some of the earliest of our great bridges are of great interest because of the originality of their conceptions Brunel, carrying the main line of the Great Western Railway on its westward course from Devon into Cornwall, found his path blocked beyond Plymouth by the Tamar, 1,100 ft. broad and, in the centre of the channel, 80 ft. deep. Nothing daunted, he designed the unique Saltash Bridge, sinking a central pier in the river by means of caissons, and so roughly halving the length of span. Curved hollow booms of wrought iron, elliptical in section and with a major

Leaving Hythe for Dungeness. Romney Hythe and D[illegible] R[illegible]

Arriving at [illegible] Road Stat[illegible] [illegible]

Two views of 15-inch Gauge Railways.



P. 20 *F.* 65.

Erecting Skew Lattice-girder span, Hampton Court Junction, Southern Rly. (p. 49)

axis of 16 ft. 9 in., strengthened by curved iron trusses, are used to carry the bridge floor, which is suspended from them by iron tie-rods. The actual width of each of the great spans is 455 ft. Although completed and opened in 1859, the Saltash Bridge still stands almost in its original form to commemorate its designer, carrying the far heavier locomotives and rolling stock of to-day. Its only drawback is the fact that the track over it is single, which causes somewhat of a " bottle-neck " over a mile of an important double-track main line.

Robert Stephenson's famous Britannia Tubular Bridge, on the L.M.S. main line to Holyhead, was his reply to the obstacle of the Menai Straits, which barred his progress from North Wales into the island of Anglesey ; this bridge was opened in 1850. Here the basis of the design was the use of two continuous rectangular tubes of wrought-iron, each 1,510 ft. long and some 4,680 tons in weight. The two tubes are set up side by side, one carrying the down line and the other the up. Three supporting towers have been set up in the middle of the straits, which are of no great depth ; the two main spans are 459 ft. across. Another case in which the moderate depth of water has allowed of the free use of supporting piers is the Tay Bridge, in whose total length of 2 miles there are no less than 85 spans. These spans are, however, of the common lattice girder type ; the longer of them measure 245 ft. each. It will be remembered that the first Tay Bridge was associated with one of the most calamitous accidents in British railway history ; the whole of the centre of it was blown down on one wild midwinter night in 1879, while the night mail was passing over, every soul on board being drowned.

In later years the general line of development, in the case of the biggest bridges, has been the use of cantilever constructions. The principle of the cantilever was known

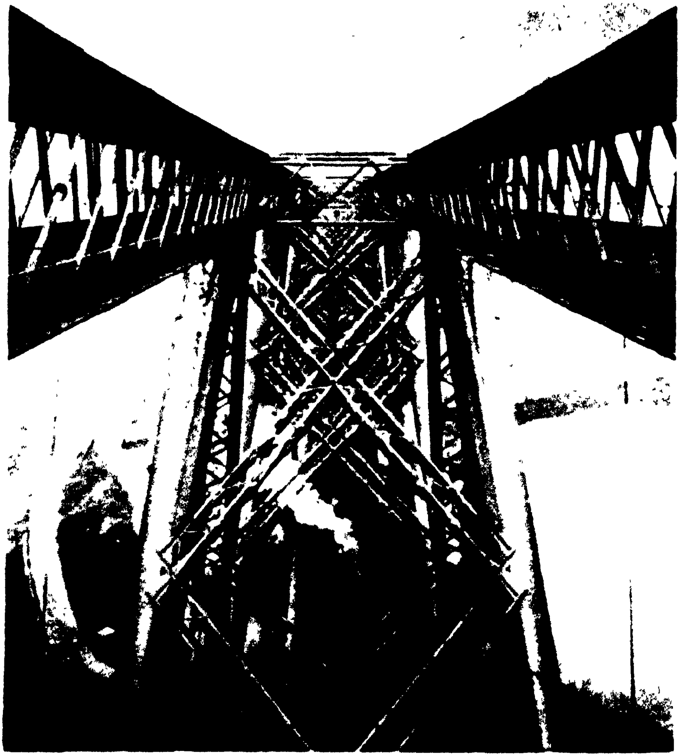
and employed even as far back as the days of the Romans, but it is the advent of steel which has allowed of the expansion of the cantilever structure to some of its colossal examples of the present day. Our own country can boast one of the most remarkable cantilever bridges in the world, which does us the more credit as a nation in that it was designed as far back as 1883. This is the Forth Bridge, to which reference has already been made. It was after the collapse of the Tay Bridge that the designs for the Forth Bridge were got out, in replacement of previous designs which, it was held, had not made sufficient allowance for the effects of wind pressure.

The general idea of the cantilever is one of balance, which property is used greatly to reduce the quantity of steelwork employed, in proportion to what might be required in the case of a girder bridge of corresponding span—if it were possible, that is to say, to build and erect an ordinary girder bridge on so large a scale. In the Forth Bridge design, the three great cantilever towers are planned with bases so broad that the enormous weight of each tower is sufficient to maintain it in a condition of stability. Not only so, but between the two side towers and the larger central tower, which is firmly founded on the island of Inchgarvie, 350-ft. girder spans are carried on the extended arms of the cantilevers, increasing the width of each of the main openings by a corresponding amount. These vast main openings each measure 1,710 ft. clear; the height of the top of the towers from sea-level is 361 ft., or more than the maximum height of St. Paul's Cathedral, and better appreciated in the striking view which forms Plate 31; and the underside of each span is 157 ft. above water-level. The 1½ miles of the Forth Bridge, including the high approach viaducts (the cantilever section of the bridge is exactly 1 mile long) swallowed up 54,000 tons of

Fig. 30.

Queen Alexandra Bridge over the Wear, Sunderland [illegible]

The bridge is a double-deck structure, carrying both railway and road



Pl. 31

The Forth Bridge

steel work, for the securing of which 6,500,000 rivets were necessary. Painting the steelwork of the Forth Bridge, to preserve it from rust, requires the perpetual services of 40 painters; the complete operation takes 3 years, at the conclusion of which a fresh start is immediately made. The only other cantilever bridge in the British Isles is also in Scotland, spanning Loch Etive, between Oban and Ballachulish; this is the Connel Ferry Bridge, which carries a single line of railway and has a span of 500 ft.

Amongst other of the world's remarkable railway bridges may be mentioned the Sukkur cantilever bridge over the Indus, in India, spanning 790 ft.; the magnificent Hell Gate lattice steel arched bridge over the East River at New York, carrying four tracks over a clear span of 1,017 ft.; the South African Victoria Falls bridge over the Zambesi, 500 ft. span; and the French Fades Viaduct, the height of whose central span above the floor of the Sioule Valley—434 ft.—probably establishes a world's record. But there is only one bridge in any part of the world which can exceed the 1,710 ft. spans of the Forth Bridge, and that is the more recent bridge carrying the Canadian National Railways across the River St. Lawrence just above Quebec, illustrated in Plate 32. This bridge has one main span, but the clear opening is 1,800 ft. A rather different principle of cantilevering has been adopted in this case, the cantilevers being of a more truly diamond shape than those of the Forth Bridge, and resting upon a kind of pin joint. To enable them to carry between them the 640-ft. span lattice girders which form the centre of the bridge, therefore, these cantilevers have to be firmly anchored in the piers at the shore end.

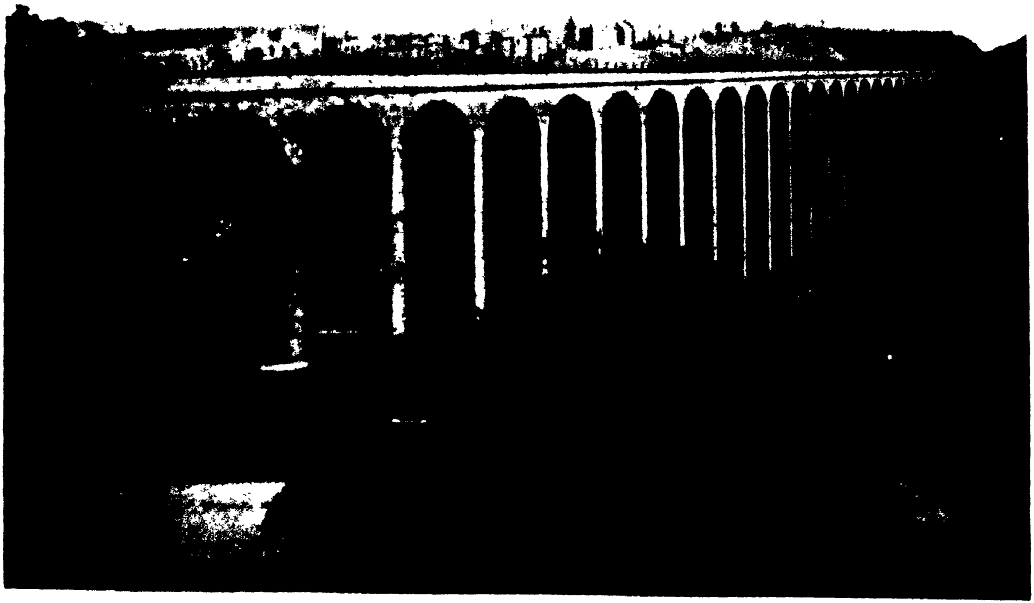
The Quebec Bridge has had a chequered history. The first design was completed in 1901, and construction had proceeded for 6 years when one of the great cantilevers

collapsed and fell into the St. Lawrence. A new and more substantial design was then prepared, and by 1910 work was once again under way. By 1916 the two new cantilevers were erected, and there only remained the task of floating down to the site and hoisting into position the central span, which had been built in a creek near by. Elaborate hoisting tackle had been prepared, but when the 5,100-ton mass of steel was in mid-air, a vital link in the hoisting gear suddenly failed, and the span fell, a crumpled mass of steel, into the river. Both these disasters resulted in considerable loss of life as well as that of material and labour; they delayed the opening of the bridge, which finally took 16 years from commencement to completion; and, needless to say, they had the effect of adding enormously to the cost of the work. They are a reminder that, as a bridge increases in size, the problem of its erection grows proportionately in its importance until at last the latter may prove even more critical than the actual design of the bridge. In all cases of bridge design the method of erection must be borne in mind, and in the large bridges erection to a large extent rules the precise design of structure which is adopted. In the building of the great Lethbridge Viaduct of the Canadian Pacific Railway, which is 5,327 ft. long, and 314 ft. above the floor of the Belly River Valley, a movable traveller was employed, erecting the lattice steel towers, dropping the plate girder spans into position, and then advancing over each span as completed. Books might be written on the fascinating subject of bridge-building alone.

Many large viaducts across inland valleys have been built in brick or masonry. Here, of course, the availability of suitable foundations is essential, as the arches of an average viaduct of this character do not span much greater distances than 50 ft. or so. Among typical British masonry

Pl. 32. *P.* 68.

Quebec Bridge, over the St. Lawrence River



F 69.

Lockwood Viaduct near Huddersfield p. 69.

viaducts may be mentioned the Welwyn Viaduct, on the London and North Eastern main line, 21½ miles out of King's Cross, whose 40 arches have an average span of 40 ft., making a total length of 1,560 ft. The maximum height above the floor of the valley is 100 ft. A longer brick viaduct on the same system, although of less height, is that which spans the Giltbrook, on the Erewash Valley line, just north of Nottingham; this has 46 arches and is 1,772 ft. long. Also worthy of note is the famous Royal Border Bridge at Berwick, opened for traffic in 1850, and carrying the East Coast main line at a height of 91 ft. above the River Tweed. A typical British masonry viaduct of fine appearance is the Lockwood Viaduct of the L.M.S. Co. near Huddersfield, illustrated in Plate 33; this has 36 spans, with a total length of 1,407 ft., and at its highest point is 129 feet above the valley.

In the construction of stone railway viaducts the Swiss have shown some remarkable skill. In that mountainous country stone is, of course, readily available, and the way in which many of these viaducts, rather than proving a blot on the scenery in which they are found, serve actually to enhance it, is a tribute to the æsthetic taste of their designers. The boldness of some of these structures is extraordinary indeed. In many cases, where the engineers have been faced with the crossing of chasms of vast depth, they have sprung their arches from the rock on either side of the ravine, without building them on abutments. Mention has already been made of certain of these viaducts in Chapter II. The Solis Bridge of the Rhaetian Railways clears the Schyn gorge with one clear span of 138 ft., at a height of 292 ft. above the river. Still more notable is the Wiesen Bridge on the converging line from Davos to Filisur, whose main arch of 180 ft. span—one of the biggest masonry spans in the world—carries the rails 289 ft.

above the Landwasser River. A few miles further down the same stream is the extraordinary Landwasser Viaduct of the line coming from the Solis direction; this is planned on a curve of 328 ft. radius, as well as a rising gradient of 1 in 50, and its six arches have each a span of 66 ft., the viaduct being 426 ft. long. The most striking feature of this structure is the way the railway is carried straight on to it out of the face of a sheer precipice, emerging directly from a tunnel on to a height of 213 ft. above the river, as seen with striking effect in Plate 34.

As yet concrete has been put to no extensive use in railway viaducts of large size, although there are one or two notable examples in which ferro-concrete—that is, concrete reinforced with steel bars—has been employed. The Swiss Canton of the Grisons, in which are situated the masonry viaducts just mentioned, claims one of the biggest ferro-concrete spans in the world. It is situated at Langwies, on the recently-opened electric line from Coire, the capital, to Arosa. This is a railway of contrasts, as the train begins its journey in the streets of Coire, but it is then carried at increasingly dizzy heights up the Schanfigg valley, until at last, at Langwies, it turns suddenly to the right and clears the valley at one bound by this astonishing bridge, with its span of 315 ft. Few who have seen this structure are likely to forget either its impressive appearance, or its sheer beauty, dazzling white against a dark green background of pines. The view reproduced of the adjacent and slightly smaller Grundjetobel Viaduct (Plate 35) shows the remarkably slender form of construction adopted.

One of the most extensive railway bridging operations ever undertaken was when the decision was reached to connect the American naval base of Key West with the Floridan coast by rail. Key West lies at the western

F 35 F 71

Grundjetobel ferro concrete bridge, Arosa R'y., Switzerland (p. 70)

extremity of a coral reef which extends for some 114 miles from the mainland. Track construction over those parts of the reef lying above sea level—or the " keys," as they are called—presented no exceptional difficulties, but the connection of these sections of track across the underwater stretches was a different matter altogether. A total of 17½ miles of bridging was needed, consisting of 11½ miles of concrete viaduct and 6 miles of steel viaduct, the latter over the deeper portions of the channels, as well as 20 miles of solid embankment in shallow water. The first 7 miles from the mainland were continuously across water from 18 to 22 ft. deep, and this immense viaduct required 316 plate girder spans of 80 ft. each, 19 of 60 ft., a swing-bridge 253 ft. long, and 210 concrete arches of 53 ft. span.

Mention of a "swing-bridge" is a reminder of the special type of underline bridge needed in cases where the railway crosses a navigable waterway at a comparatively low level. If the underside of a bridge or viaduct of the ordinary type will not clear the masts and funnels of vessels passing along the waterway, it is necessary for the railway to construct an opening bridge. Such bridges are of various types. The oldest is the " swing-bridge," pivoted in the centre, and swinging at right-angles to the line when it is desired to open the waterway ; a typical example of this type is seen, open and closed, in Plate 37. Chief among the objections to this type of the bridge is the fact that the supporting pier obstructs the channel ; to meet this objection the support is sometimes moved to right or left of the centre, which increases the width of channel on one side of it while reducing that on the other. But a more popular, though more expensive, type of opening bridge is the " rolling lift " bridge, in which the opening span is hinged and heavily counterweighted at one end, the whole span rising vertically in the air about its hinge when opened.

A fine example of this kind (Plate 36), built on the Scherzer "rolling-lift" principle, crosses the River Trent, near its mouth, carrying the Doncaster and Grimsby line of the L.N.E.R. There is yet another type of opening bridge, used occasionally in America, in which the whole of the opening span rises horizontally to the desired height, by means of hoisting gear in towers on either side, as illustrated in Plate 38. But this does not afford so clear a channel as the hinged type of opening span.

From bridging we pass to tunnelling. Tunnels are so costly of construction that they are avoided when any alternative location is at all possible, but even in the excavation of a cutting there comes a depth at which a tunnel is the less costly expedient of the two. Occasionally, a kind of tunnelling known as "cut-and-cover" is resorted to, which does not, like the true tunnel, require recourse to boring. This is when the railway is only just below the ground level, but for some reason requires covering over. The "Inner Circle" of the London Metropolitan and Metropolitan District Railways, except where it comes out into the open, is entirely of this character. A cutting was excavated throughout to the railway level, and then roofed over, the expression "cut-and-cover" giving an admirable description of the operation.

Boring the deep level tubes of London was another matter altogether. Depth was sought both in order to avoid disturbance to the buildings above and also to avoid interference with the complex network of gas, water and electric mains, telephone conduits, sewers and drainage, that exists below the surface in a great city like London. The actual depth of the tubes below ground varies with the location, but may be taken at an average of about 90 ft. It was Peter Barlow who, in sinking cast-iron cylinders in the middle of the Thames for the construction of Lambeth

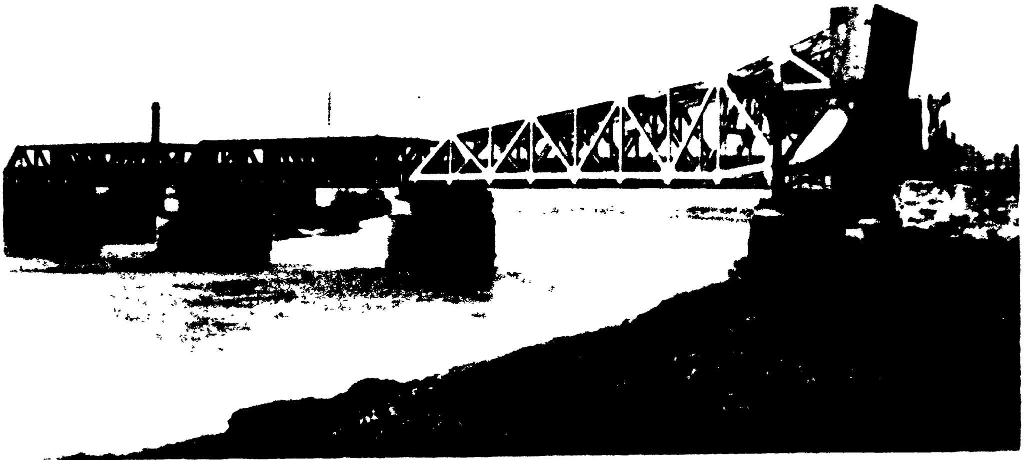
Bridge in 1862, conceived the idea that "cast-iron cylinders of similar construction might be driven horizontally under rivers with perfect safety." In 1870 he obtained Parliamentary powers to carry an under-river subway on these lines from the Monument in the City to St. George's Church in the Borough, passing under the Thames, but the project lapsed for lack of financial support. Where Barlow failed, however, his pupil Greathead succeeded. Powers were obtained to construct the first tube railway, from King William Street to the Elephant and Castle, in 1884, and for an extension to Stockwell in 1887. This line, both the first tube railway and the first railway in the world to be electrically worked, was opened in 1890. To-day no less than 50 miles of twin tube tunnels have been driven under the Metropolis of London, and through them it is possible to make the longest continuous underground journey in the world, as the Edgware and Morden tube trains remain in tunnel for no less than 14 miles, rivalling the length of the Simplon Tunnel.

The actual boring of the tubes is a matter of great interest. Greathead, whose name figured in the last paragraph, developed the method which is in general use, known as the "Greathead Shield." The shield itself is circular, like the barrel of a drum and of the same size as the tunnel, and it encloses a circular steel cutting edge, like two lengths of a telescope. The cutting edge is driven slowly forwards, by hydraulic pressure exerted against the completed tunnel behind the shield, and as it moves navvies shovel away the material into which the edge has cut. Inside the shield the tunnel itself is built, consisting of arc-shaped heavy cast-iron segments bolted together; the shield is then drawn forwards, and the space that it occupied, between the tunnel and the limit of the excavation, is filled in by "grouting"—that is, by running

in liquid cement under pressure. A later development of the Greathead Shield is the "Price Rotary Excavator," seen in detail in Plate 39. In this ingenious appliance the cutting edge is replaced by an immense wheel of the same diameter, carrying on its six spokes large cutters. As the shield advances, these cutters revolve, and the work of the navvies in the shield is thus greatly simplified. With the use of the rotary excavator, it has been found possible to drive tube tunnels through London clay at the rate of 20 to 25 feet a day.

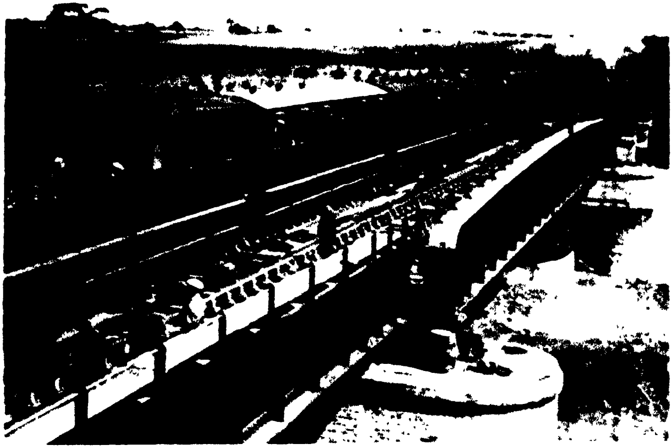
Tube tunnels are of a considerably smaller diameter than tunnels built to accommodate ordinary rolling stock. They carry single tracks throughout, and except on curves, where the size has to be slightly increased, the diameter of each tunnel is usually 11 ft. 9 in. Passenger space inside the tube cars is obtained by building the floors considerably nearer rail level than those of the ordinary coach. Of the London tubes, only the Great Northern and City is of sufficiently large diameter to take full-size coaches, this line having been planned to connect up with the London and North Eastern system at Finsbury Park (to allow for the through running of trains off the Great Northern suburban lines), but the necessary physical connection has never yet been made. By comparison with the tubes, the diameter of an average double-line railway tunnel is 25 to 26 ft., and boring in the latter case is, of course, a considerably more costly operation.

The boring of tunnels is by no means confined to the penetration of such soils as London clay. In mountainous districts rock usually has to be dealt with throughout the length of the tunnels, and this has to be drilled laboriously with rock drills, and then blasted away, until at last the way has been made for the railway. It might well be imagined that the bore thus made would be secure



P. 30 P. 74

Keadby Bridge across the River Trent, L.N.E.R. (p. 72)



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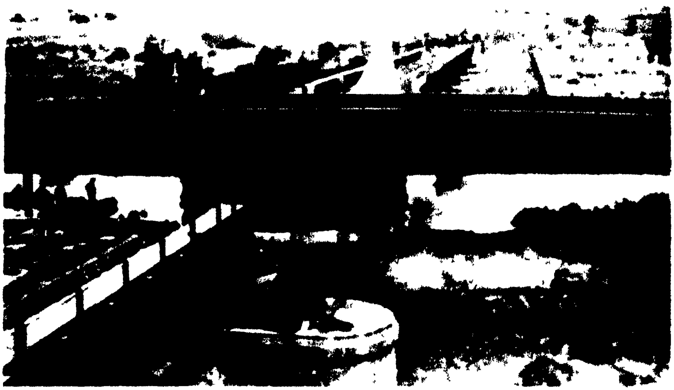

P.. 37 [illegible]

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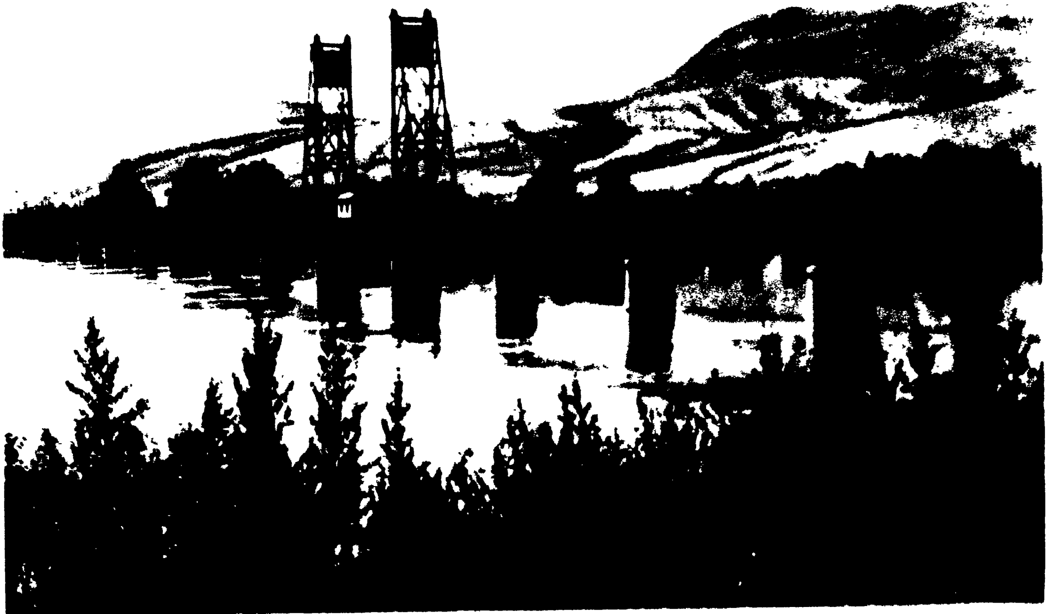
enough to leave without a brick lining, but this is rarely the case. Only through the hardest rock, such as gneiss, is it possible to do away with lining, but most of the world's longest tunnels are lined with masonry throughout. In the Simplon Tunnel even masonry lining was not sufficient; the pressure of the overlying rock, as the bore went deeper and deeper under the mountain, became so enormous as to threaten to crush the tunnel lining like an eggshell, and steel constructions of great strength (Plate 40) had to be used to reinforce the masonry. Elsewhere, through rotten rock, specially substantial timbering (Plate 40) was necessary during construction. Another exceptional difficulty experienced in driving the longest tunnels is usually that of temperature, which rises proportionately to the depth of the workings below the surface. In boring the Simplon, where the temperature rose finally to 127 deg. Fahr., it was only found possible to keep the workers at the face by pumping into the workings supplies of air which had been refrigerated by passing them through sprays of ice-cold water.

It is seldom in tunnel construction that, in some form or other, the unexpected does not happen. The greatest of all enemies in tunnelling is usually water. Wherever possible, trial borings are made along the route of the tunnel, in order to ascertain the nature of the soil to be penetrated, but the depth of some of the longer tunnels below the surface often renders this impossible. Britain's longest tunnel—the 4⅓-mile bore of the Great Western Railway under the River Severn, costing roughly £2,000,000—suffered badly in this respect. Water broke into the workings both from the river bed and from the ends (owing to the tidal wave, known as the "Bore," which sweeps regularly up the estuary at certain periods), and, yet again, from a vast underground flow of water called

the "Great Spring." At more than one stage of the work it was necessary to employ divers in order to carry on, and when the tunnel was at last finished, after 11 years of strenuous labour, it was only possible to keep down the percolation of water from the "Great Spring" by the installation of powerful pumping machinery, which to-day is still pumping water out of the tunnel at the rate of 20,000,000 gallons daily.

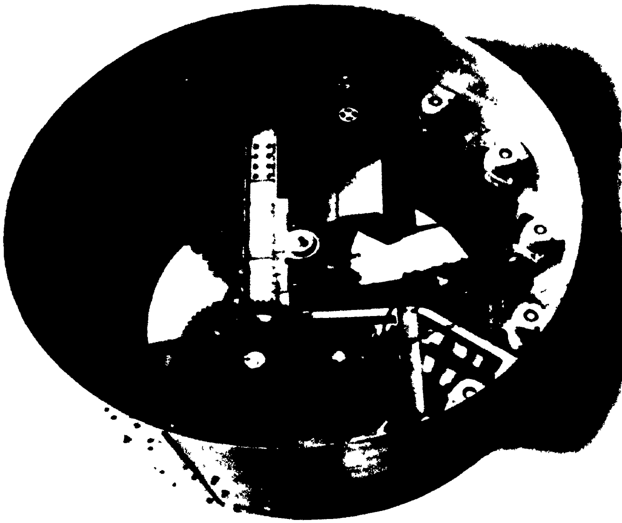
In most of the Swiss tunnels, the tapping of underground streams during the course of boring has greatly hindered the prosecution of the work. A still more calamitous happening delayed the completion of the Lötschberg Tunnel. The bore had been carried 3 miles from the Kandersteg portal when suddenly the workers penetrated the floor of the Kandertal—a valley above, whose extreme depth the preliminary surveys had failed to verify—and let in a great mass of glacial debris and a torrent of water. The workings were immediately flooded out, and 25 of the men were drowned. For a long time the work was stopped; then the decision was reached to abandon nearly 1¾ miles of completed tunnel, to stop up the original bore at a distance of 1½ miles from the entrance, and to divert the centre-line of the tunnel to the eastwards, well out of the danger-zone. This was done with success, but, of course, at a cost far exceeding the estimate for the tunnel; and the misfortune is made apparent as one studies the plan of the tunnel, which is straight for roughly one-half its length from the south portal, and then bends eastwards for a considerable distance, being brought round again to the original line a short distance from the north portal. In this way the planned length of the tunnel, which was 8½ miles, has been increased to an actual length of 9¼ miles.

As regards time, the 9¼-mile St. Gotthard Tunnel took



Pl. 38 F 76

Kamloops Viaduct, with lifting span, Canadian National Rlys p. 72



8 years to complete and cost £2,250,000; the 12¼-mile Simplon Tunnel occupied the same time, and consumed £3,000,000; the Lötschberg Tunnel, despite the tragic happening just referred to, was completed in 4½ years, and the whole 46 miles of line, including 33 tunnels other than the main bore, and 22 bridges and viaducts, was carried through for £3,320,000. Some of the most rapid rock-boring on record was carried out in the Connaught Tunnel (Plate 11) of the Canadian Pacific Railway, referred to in Chapter II; by the running, for the first time, of a "pioneer bore" of small diameter, parallel to the main bore, the 5 miles under Mount Macdonald were pierced in just over two years, and the main tunnel, 24 ft. high and 29 ft. wide, was complete and ready for use in 3½ years after commencement. A permanent expense in connection with many of these long tunnels is the maintenance of pumping machinery in order to keep them supplied with fresh air, as it is not possible to bore the ventilating shafts which, like great chimneys, draw the smoke-laden air out of most of our tunnels, and so purify their atmosphere. The Connaught Tunnel, just mentioned, has one of these pumping plants, as has also our Severn Tunnel. Through the long Swiss tunnels the working of trains is now entirely electrical, and except in the Simplon, where pumping is still resorted to in order to moderate the temperature, this air supply is not needed. A list of the longest railway tunnels in the world is found in Appendix C.

Before leaving the subject of tunnels, it is necessary to mention tunnels of an unusual description, whose use is confined to mountainous country. In countries such as Switzerland, liable to heavy snowfall in the winter, the steep mountain slopes encourage great snowslides, or avalanches, especially during the spring and early summer when the snow is melting. The bigger avalanches, starting

high up in the mountains, and gathering momentum as they descend, can be and sometimes are very destructive in their action, as they bring down great masses of ice and even of rock, as well as the snow. Where avalanches follow regular and well-defined tracks, it is possible for the railways in their path, which otherwise would probably be swept away, to make due provision for their safety. This is done by the construction of special avalanche tunnels, which nowadays are solidly built in concrete, and serve to throw the avalanches clear over the line. Many examples of this type of avalanche protection can be seen along the route of the Lötschberg Railway in Switzerland, especially between the south portal of the Lötschberg tunnel and Brigue, where avalanches are of frequent occurrence. In addition, heavy masonry walls are erected at intervals high up the hillsides, in order, as far as possible, to " train " the course of the snow-slides into these regular tracks.

Elsewhere—in the Canadian Rockies, for example—extensive use is made of timber snowsheds, completely enclosing the track for long distances, at points where experience has proved that the snow is likely to " drift," and so to bury the line. One of the most singular railway protections in existence against the destructive effect of avalanches is found on the recently-opened Furka-Oberalp Railway of Switzerland. Between Hospenthal and the Furka the railway crosses Steffenbach gorge, at a high altitude, where more than once the bridge provided was swept away by avalanches during the winter, when the line was, as usual, closed to traffic. The engineer of the railway has now devised a most ingenious collapsible bridge (Plate 41), which, on the cessation of railway traffic for the winter, is taken to pieces with a minimum of trouble and stored on both sides of the gorge, while before the opening of the

Pl. 40.

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summer service it is rapidly re-erected for use. As the line is only of metre gauge, the locomotive and rolling stock are of no great weight, and the problem was not so severe as it might have been on a standard gauge railway.

It should be mentioned at this stage that all railways exposed to severe winter conditions, and especially lines running through mountainous country, have to make provision for the clearance of heavy snowfalls and drifts. In our own country snow-ploughs in the form of steel rams attached to the front of the engines (Plate 46), shouldering the snow to right and left of the line as they advance, usually suffice. But in countries like Sweden and Norway, and over the higher mountain lines of Switzerland and across the Rockies in America, power-driven rotary ploughs are necessary, to cut through the snow and throw it clear of the track. A fine electrically-driven Swedish snow-plough is seen in Plate 46, and in Plate 42 is a striking view of a steam-driven plough at work near the summit of the Bernina Railway in Switzerland, where drifts up to 17 ft. 9 ins. in depth have been cut through with ease.

Reverting for a moment to tunnels, we may note that the longest British tunnels, apart from the Severn Tunnel, all penetrate the Pennine range, or, as it is called, the "backbone of England." It is a matter of no small interest, as illustrating the bearing on railway planning of physical geography, to look at a map and see how the railway networks of Lancashire and Yorkshire converge into comparatively few trunk lines for the passage of the Pennines. Most of these have to pass through tunnels of considerable length. The L.M.S. line from Sheffield to Manchester first finds its way through Totley Tunnel, 3·6 miles long, and then Cowburn, 2·1 miles, between Dore and Chinley; at Chinley it joins the Midland main line from London, which has just penetrated the 1·7-mile

Dove Holes Tunnel, and the two together go through Disley Tunnel, 2·1 miles long, on their further progress to Manchester. The rival Great Central main line of the L.N.E.R. has to be carried under Woodhead Tunnel—two parallel single-line bores of just over 3 miles—in connecting the same two cities. Of the same length are Standedge Tunnels on the L.M.S. main line from Leeds and Huddersfield to Manchester; here four tracks are carried under the mountains in three separate tunnels. The other chief tunnel in the north of England is Bramhope, on the L.N.E.R. between Leeds and Harrogate, 2·1 miles long; while the West of England boasts Sodbury, on the G.W.R. Badminton "cut-off" to South Wales, 2·5 miles long, and in the east is found Sevenoaks on the Southern, all but two miles in length. The longest British railway tunnels are set out in detail in Appendix D.

The engineering works of the railway are not confined alone to bridging and tunnelling. Excavation and embanking are between them no small problems. In the preliminary planning, it is important that the amount of material required to tip the embankments shall be roughly balanced by that which is excavated from the cuttings; otherwise extra land must be bought, either on which to dump surplus spoil from the cuttings or from which to cut the material required to complete the banks. Embankments of exceptional depth, such as the 110-ft. Pequest "Fill" of the Delaware, Lackawanna and Western Railway of the U.S.A., are generally explained by the fact that an abnormal amount of filling was available out of the cuttings, or, alternatively, that the floor of the valley offered insecure foundations for a viaduct. Deep cuttings, again, like the 60-ft. Tring Cutting or the 80-ft. Roade Cutting of the L.M.S. main line to Scotland, replace tunnels because of the excavated material being needed for adjacent em-

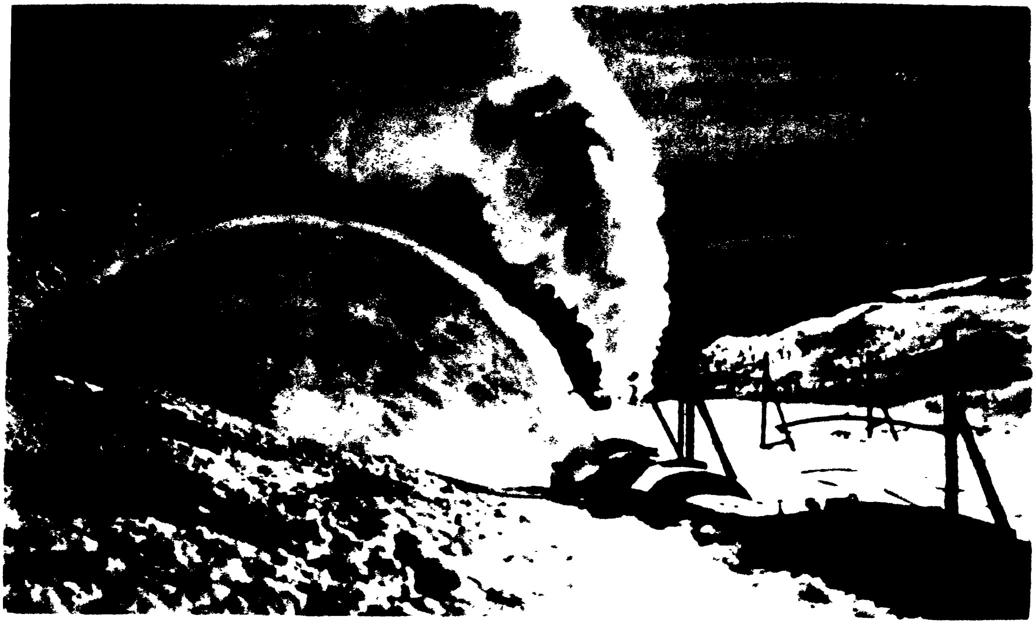

Fig. 42. p. 80

Clearing Snow with the Rotary Plough, Bernina Rly., Switzerland p. 7[illegible]

The Railway at this point is 7,000 ft. above sea level, but is kept open [illegible] winter

[illegible]

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bankments. Occasionally tunnels whose maintenance has proved expensive—especially tunnels in which there have been difficulties of subsidence caused by colliery workings underneath—are "opened out"; that is to say, they are converted to cuttings, by the removal of the overlying soil or rock.

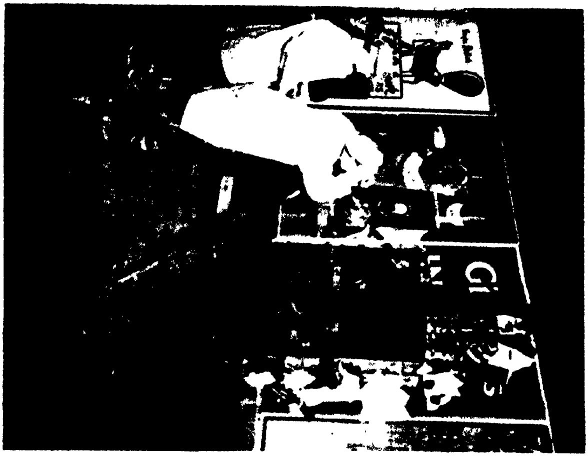
The nature of the soil through which the railway is cut regulates the "slope" of the embankment, and, at the same time, the width of land which is required. Rock will stand up vertically, and so will chalk, the chalk cuttings of Kent, such as that at Knockholt, being doubtless familiar to every reader who has travelled by the Tonbridge main line of the Southern Railway. Clay soil, on the other hand, requires a very flat slope; 1 in 2 or sometimes even 1 in 3 will barely suffice to keep this treacherous soil in place in wet weather. Careful drainage is often necessary, and this explains the curious stripes which are often seen decorating railway banks, sometimes vertical, and sometimes with "trunks" branching as they ascend, like trees in appearance. These are in reality deep cuts downwards into the bank, filled with broken brick or rubble, to allow of the rapid draining away of the surface water.

A few words are needed, in concluding this chapter, as to the work of building a new line. As a preliminary, the route has been surveyed by the engineers of the railway, who now conduct, with great accuracy, the operation of "setting-out," marking the centre-line of the railway with pegs at stated intervals. Meanwhile drawings have been prepared of all the structures *en route*, and careful profiles of the gradients, with the cutting and embanking necessary to form the "grade." Contracting firms are now invited to "tender" for the work of construction, and tenders—usually, for obvious reasons, the lowest—having been accepted, the work is begun. If it is a line of any extent,

the work of construction will probably be divided between several firms. The land required for the line, which, by the Act of Parliament, the railway has compulsory power to acquire, at a reasonable valuation, is first of all fenced; and then the contractor lays down his temporary railway. This is an "overland" route, and is to enable him to transport his materials and stores from point to point.

Great excavators, or "steam navvies," as they are called, get to work on the cuttings, beginning at the point where an embankment is planned to merge into a cutting, and then gradually working their way inwards, while the material that they excavate is being run further and further outwards on to the embankment in the opposite direction. Underline bridges begin to rise in the middle of open country, along the route, like gaunt sentinels, waiting until the adjacent embankments are tipped up to their abutments. Tunnels, which require the most accurate of all setting-out work on the part of the engineer, are begun from both ends simultaneously, and it is rarely—even in the longest Swiss tunnels, where the surveying "traverse" has been made right over the tops of the mountains—that the meeting of the two bores in the centre of the tunnel is as much as an inch or so out of line. The setting out of tube tunnels requires special methods, illustrated in Plates 43 and 44, which show the surveying above ground, carried on at night, and then the transfer of the centre-line by theodolite below ground through the service shaft.

As each of the cuttings and embankments is finished, and as each section is joined up by the completion of the intervening bridges, so the permanent track—whose description requires Chapter V to itself—is laid along the route, and the contractor's temporary track can be abandoned. All the stations and depots along the line are in course of erection at the same time; sidings and goods



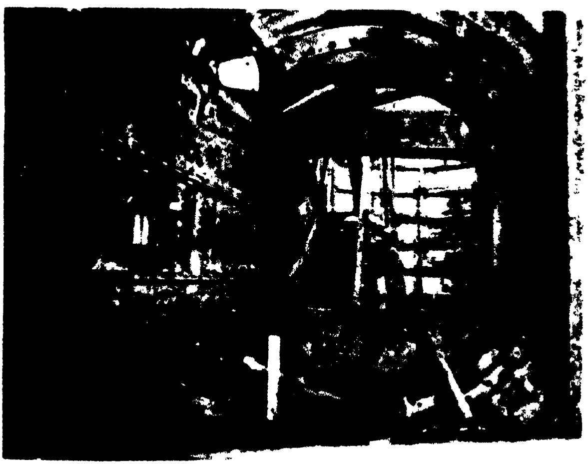


Fig. 45 G 83.

Typical American Track Lay-out Near Oakland, Southern Pacific Rly. (p. 86)

yards are laid out; signals and signal-boxes, with all their complex operating mechanism, spring up along the line; and all the myriad details connected with the working of a railway begin to appear. The last event before formal opening, in our own country, is the visit of the Government Inspector, representing the Ministry of Transport, who is charged to satisfy himself that the railway may safely be run over; bridges are tested; the whole of the signalling is very thoroughly examined; and, if all is in order, the necessary permission to open is given. So the railway is complete; and the constructional engineer now hands it over to the maintenance engineer who will be responsible for its upkeep.

CHAPTER V

The Permanent Way

When the sub-structure of the line has been completed, the remaining task is that of laying the track. It is to the track itself that the title " permanent way " is usually applied, although in point of fact it constitutes one of the least permanent parts of the railway. The stresses to which railway track is subjected are of extraordinary severity, especially where the traffic passing over it is fast, heavy and continuous. Under the combined pounding and rubbing action of the wheels, the upper surface of the rails is gradually abraded away, while the cast-iron chairs in which they rest in course of time begin to indent the rails on the underside. It was for this reason that the " double-head " rails of early days were abandoned ; it was intended that, after they had been worn down on the upper surface as far as was regarded safe, they should be turned upside down, and sustain the same amount of wear on the other head, so roughly doubling their life. But when they were turned, it was found that the lower head had become so " chair-marked," if the rails had been in use for any length of time, that smooth running of the trains over them was impossible.

So the " double-head " rail ultimately developed into our present " bull-head " section (Fig. 11), in which the head of the rail is of a larger cross-sectional area than the foot. The section itself is so designed that the head may

safely be allowed to wear down until it is approximately equal in cross-sectional area to the foot; the time has then come for its renewal. On a straight track the wear, as may be expected, is chiefly on the top of the head; but on sharp curves the pressure of the wheel-flanges against the outer rail of the curve results in a troublesome wearing away of the rail at an angle, known as "side-cutting."

Every observant reader who has travelled on the Continent has probably noticed the difference between the type of railway track in use abroad and that of our own country.

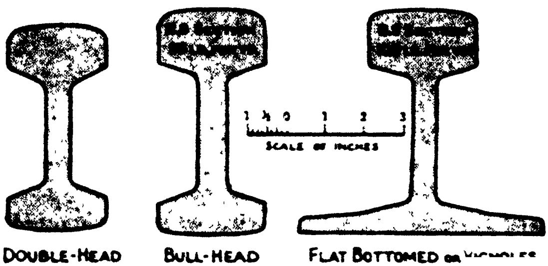


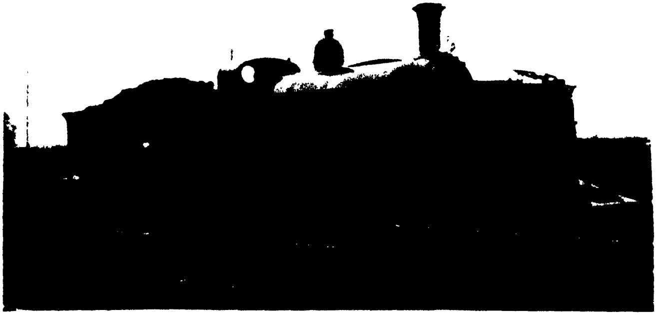
FIG. 11.—Typical Rail Sections.

Instead of holding the rail securely in a cast-iron "chair," as we do, Continental railways use a flat-footed rail which requires no chair. This type of rail was introduced by Charles Vignoles, by whose name it is often known. Rapidly it came into favour in the early days because it could be spiked down direct to the sleepers, a matter of no small advantage to railway pioneers in undeveloped countries, who could cut their sleepers from neighbouring forests, and then needed only to transport their rails and fastenings to the scene of operations. In this way the flat-bottomed rail has, with one or two exceptions, become standard for

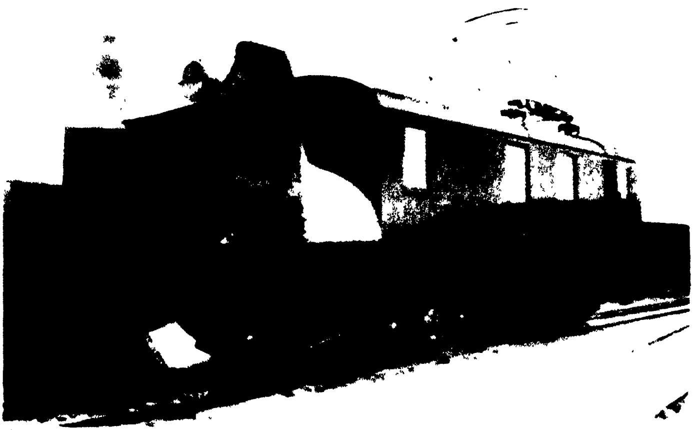
railway work in every country but our own. But nowadays a "sole-plate" of steel is usually interposed between the flat-bottomed rail and the sleeper, designed, like the chair, to spread the weight of the moving load over as large an area of the timber as possible, and so to increase its life; thus the flat-bottomed track of to-day has but little advantage in cost, or the number of its parts, over "bull-head" track. Typical examples of American track so laid are seen in Plates 45 and 157. Endless arguments have taken place as to which of the two is the cheaper to lay and to maintain, and which affords the smoother riding, but the question has never been settled. Certain it is, however, that no other country can rival the solidity of track construction to which we are accustomed in Great Britain; the chief of our main lines can safely claim to have the finest permanent way in the world.

As the weight and speed of trains have increased, it has been necessary proportionately to increase the weight of the rails. British railways have now settled down to a standard type of track, consisting of rails weighing 95 lb. to the yard, for main line use, and 85 lb. rails in branch lines. Rails of 100 lb. per yard section have been tried, and on some lines have been used fairly extensively, but for certain reasons connected with manufacture, the larger head of the 100 lb. rail was found to offer but little, if any, extra wear, and the railways in question are now using 95 lb. rails instead. In the same way the chief American railways increased their heaviest flat-bottomed rails for main lines to 130 lb. per yard, and in some cases even more, but there is a present tendency to revert to rather lighter sections.

The joints between the rails, of which we are reminded constantly while travelling by the rhythmic jolts, as the wheels pass over them, are the weakest part of the track,



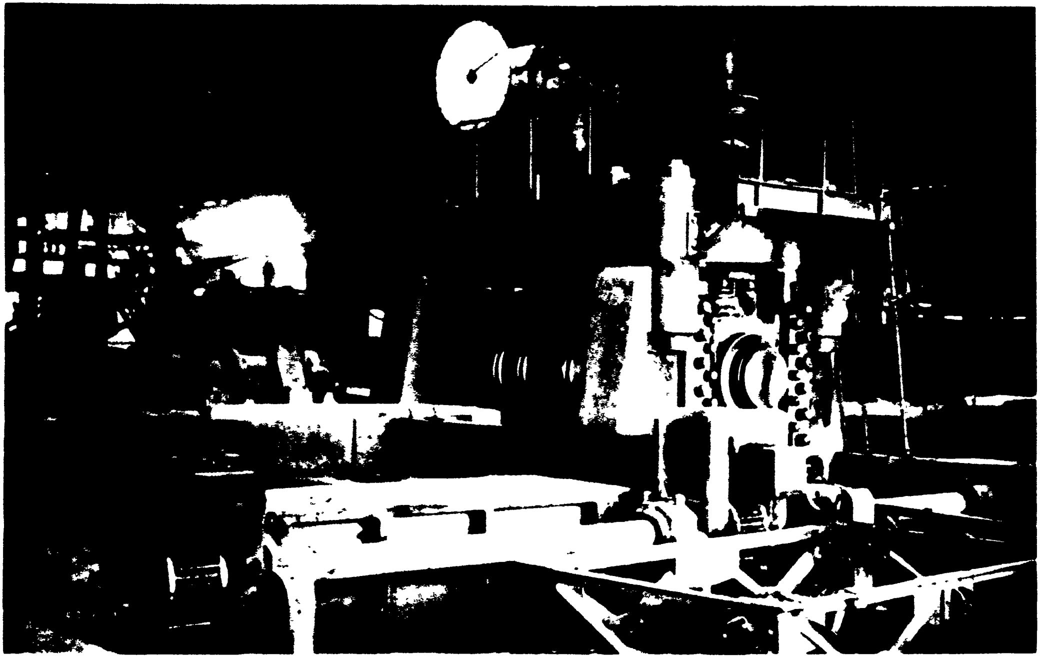
[illegible] L.N.E.R.



Pl. 40 [illegible]

Electrically [illegible] Sweden

Types of Snow-plough [illegible]



Pl. 47 G 87

Rolling-mill used in Steel Rail Manufacture (p. 80)

and it is therefore an advantage to cut them down in number as much as possible, by the use of longer rails. So the length of British rails has worked up by degrees from 24 ft. to 30 ft., 36 ft., 45 ft., and, in the case of the L.M.S. Railway, to 60 ft. The last-mentioned has just become the standard on the L.N.E.R. also, but the most widely-used present length is 45 ft. 60 ft. rails of the 95 lb. section, which weigh 17 cwt. each, have to be handled with cranes. Continental railways in the past adopted a length of 12 metres (39 ft. 4½ in.), but the leading main lines of France are now going in for 18-metre (59 ft. 1 in.) rails. America still sticks mainly to lengths of 33 ft. and 40 ft.

For the upkeep of British railways alone, some 250,000 tons of rails are required every year. The actual life of a rail before it needs renewal naturally varies according to the particular location in which it is laid. On some of the busiest stretches of the London Underground lines, where electric trains follow one another at the rate of forty to the hour, six or nine months' wear may call for the renewal of the rail; in country districts, on the other hand, rails have been known to remain in service for 40 years, and even more. But the quarter-of-a-million tons of steel swallowed up annually in rail renewals is in itself a witness to the vital importance of using as hard-wearing a rail as possible. Both the exact section of the rails laid in this country, and the chemical composition of the steel used in their manufacture, have now been settled by a body of experts known as the British Standards Committee, as a result of whose deliberations there has been produced the "British Standard Specification" to which British rails are made.

It would be quite impossible, in the space at our disposal, to go into the technicalities of manufacture, but the analysis which is worked to may be of interest to those readers who have chemical inclinations. It is given overleaf.

Carbon	.. .. ..	From 0.55 to 0.65 per cent.
Silicon	.. .. ..	From 0.10 to 0.30 ,,
Sulphur	.. .. ..	Not to exceed 0.05 ,,
Phosphorus	.. ..	,, ,, 0.04 ,,
Manganese	.. ..	,, ,, 0.80 ,,

This is the analysis for the basic open-hearth steel process, by which the bulk of British rail steel is now manufactured. The remainder of the analysis—between 98 and 99 per cent. —consists almost exclusively of iron, and it will doubtless be a matter of surprise to the reader who has not studied these things that such minute proportions of the other elements named can so influence the physical properties of the metal. For hardness reliance is placed chiefly on the carbon; for toughness and freedom from brittleness the manganese is largely responsible; silicon, too, purifies the steel and helps it to resist the tendency to break; but sulphur and phosphorus encourage fractures, and must be kept down to the lowest possible limits.

In order that proof may be forthcoming that the rails are sufficiently hard, and yet are free from brittleness, tests are made on the steel of every "cast," or separate make of steel that is tapped from the open-hearth furnace. The principal test consists in taking a 5 ft. length of the finished rail, standing it with head uppermost across supports 3 ft. 6 in. apart, and then—in the case of the 95 lb. per yard bull-head rail—dropping on to its unsupported centre an iron ball of one ton in weight, from heights of 7 ft. and 20 ft. in succession. As a result of this severe punishment, the piece of rail bends, but it must not break; neither must it deflect in the centre more than 4 inches, as a greater deflection would indicate that the steel was too soft, and would quickly wear away in service. Other tests are made, but on these we have not time to dwell.

For places where the wear of the rails is exceptionally rapid, alloy steels are sometimes used. Of these the most

remarkable in its properties is manganese steel, containing between 12 and 14 per cent. of manganese, which has a "life" some six or more times that of ordinary steel, and has no rival in the resistance that it offers to the abrasive action of the wheels. But it is terribly expensive, and for that reason finds but a limited use, where the wear of ordinary rails is excessively rapid. An example of manganese steel track construction is seen in Plate 48, which shows the extensive system of cast manganese steel crossings laid at the east end of Newcastle Central Station. Rails containing small percentages of nickel and chromium are used fairly extensively, where specially hardwearing rails are needed. But by far the major proportion of the 250,000 tons of rails already referred to are rolled from steel of the composition already described. Only one British railway goes to the length of rolling its own rails; it is the L.M.S., in whose vast locomotive works at Crewe it has been said that everything required for the railway is made, "from finished locomotives to wooden legs for the staff"—when they are unfortunate enough to lose them in accidents. A modern electrically-controlled rolling-mill used in the production of steel rails is shown in Plate 47.

The remaining constituents of the track now need brief attention. The rails are secured together by "fish-plates," or, as the Americans call them—and with rather more reason—"splice-bars." These are so designed as to leave, normally, a space of ¼-inch between each pair of rails, to allow of expansion in warm weather. The need of this precaution is well illustrated by a curious phenomenon connected with railway track, known as "rail creep." Very slowly, but none the less surely, the whole of the rails begin to "creep" in one direction; it is generally, though not always, in the direction of running of the trains, and

is supposed to be partly due to the constant succession of blows that the rail-ends receive from the wheels, and partly to the effects of expansion and contraction. You can often see how creep has been at work by the way in which the sleepers at a rail-joint have been forced out of the square, in consequence of one rail having crept more than the other.

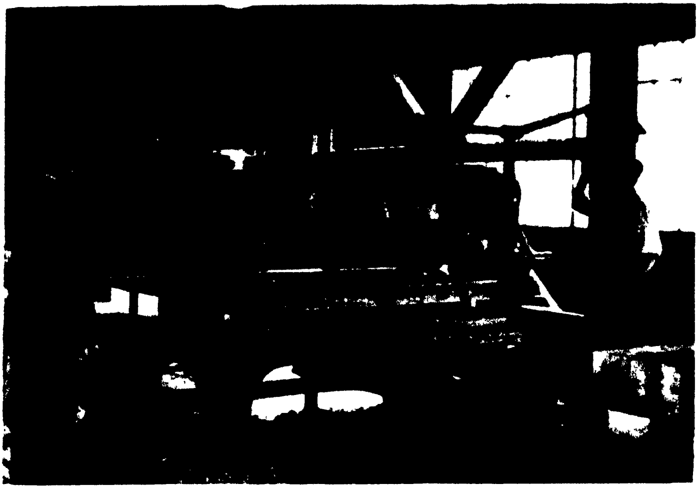
The result is that the rail-joints at one part of the track begin to open out, as far as the connecting bolts will allow, and further ahead—perhaps where some complicated switch and crossing work is met with, the track being here more securely anchored—they close up. On not a few occasions disastrous derailments of trains have taken place because these closed rail-joints have not been noticed in time, with the result that the track, finding no possibility of expanding lengthwise between a cold night and a warm day, has retaliated by buckling out of shape altogether. Considerable trouble is given to those responsible for the maintenance of the track by the necessity, from time to time, of "pulling back" the rails into their correct positions, where the creep has been severe. Attempts have been made, more particularly in America, to fix the track securely in place by means of what are called "rail anchors," and these generally succeed in reducing the rate of creep, though they seldom arrest it altogether.

Chairs are of cast-iron, made in enormous quantities in foundries which are specially equipped for the purpose. British railways now use standard types of chairs, the chair employed with the 95 lb. rail being of 46 lb. weight. As previously mentioned, the base of the chair is designed to spread the weight of the moving load over as large an area as possible of the timber of the sleeper. Across the base there is moulded a curved seat, on which the rail rests comfortably, between two upstanding jaws. The lower of

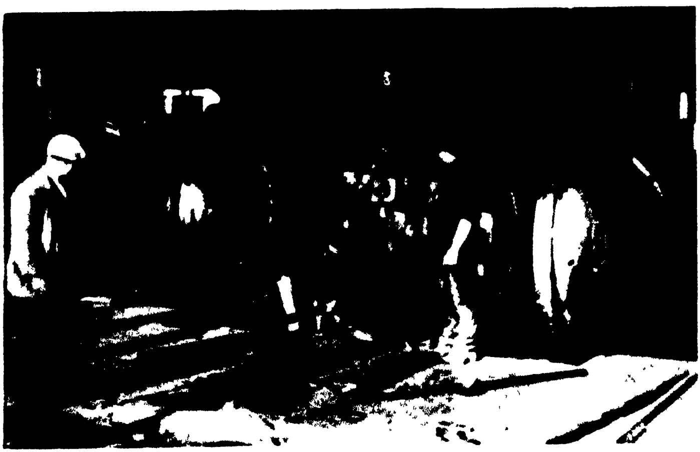
Pl. 48.

The "Queen of Scots Pullman" entering Central Station, Newcastle, from East End (p. [illegible])

The engine is running over the special lay-out of crossings east from [illegible] (p. [illegible])



Sleeper Boring Machine [illegible]



P. 50 Col.

these fits accurately into the centre of the rail ; between the rail and the higher jaw, which is arranged on the outside of the gauge, there is inserted a wooden wedge, or " key," generally of compressed oak or teak. This is driven in the direction of running of the trains, whose motion tends to wedge the key still more tightly in position. When the rail is keyed up in the chair, it is held very slightly out of the vertical, at an angle of 1 in 20, the two rails of one track being thus tilted towards one another. The centre-line of the rail is thus at right-angles to the " coning " of the wheel tyres ; and an additional advantage is that the rail would lie in its correct position, even if all the keys were out.

For securing the chair to the wooden sleeper, it is now the practice to use three large screws, weighing 1½ lb. each, and galvanized to resist the ravages of rust. On railways abroad, plain dog-spikes were once used to secure the feet of the flat-bottomed rails, but these have now given place, for the most part, to screws, which afford a much more secure fastening. In our own country the " chairing " of the sleepers is usually done by automatic machinery. In an endless chain the sleepers pass, first to an adzing machine, which planes flat seats on which the chairs may rest ; then to a boring machine (Plate 49), which simultaneously bores all the six holes required for the screws ; the chairs are then dropped into their places, wooden ferrules are inserted in the screw-holes, and after them the screws ; and the last operation is that of screwing up by machinery. So the sleepers are sent out to the place at which they are to be used all ready-chaired, and much time is thus saved at the site. On main lines it is often the practice to insert a thick pad of felt between the chair and the sleeper, to deaden the noise as the trains pass over the track and to improve the running.

Sleepers constitute one of the biggest problems that the maintenance engineers of the railways have to face. Their function is both to tie the two rails of each track together, exactly to gauge, and also to distribute the weight of the trains over the ballast. In its famous broad gauge days, already referred to, the Great Western Railway laid its rails on longitudinals (instead of the ordinary transverse sleepers), held together at intervals by iron tie-bars, but such construction is seldom favoured nowadays, except occasionally across bridges and viaducts. The ordinary sleeper, or "tie," as the Americans call it, is 9 ft. long by 10 in. wide by 5 in. deep, enormous quantities being required annually, not only for complete renewals of track, but also to replace sleepers here and there which have decayed or split in service.

It is the gradually increasing scarcity of the world's timber that is the problem—not so acute to-day as it will be one day, but nevertheless serious, on the ground of the cost of the timber alone. The life of the sleepers is prolonged to the utmost by preservative treatment before they are used. They are first of all seasoned in great stacks, which you may see at the various sleeper depots, such as Hayes on the Great Western, Northampton and Ditton on the London, Midland and Scottish, Lowestoft and Boston on the London and North Eastern, and elsewhere. Then they are passed into big creosoting cylinders (Plate 49), where the air is exhausted, and creosote oil is pumped in, under pressure, until each sleeper has absorbed from 3 to 6 gallons of it. This creosote is to prove the chief means of resisting the effects of damp, as the sleeper lies in the ballast, which would otherwise rot it through in a very short time.

Many substitutes have been tried for the timber sleeper. On certain railways in India and elsewhere, the rails rest

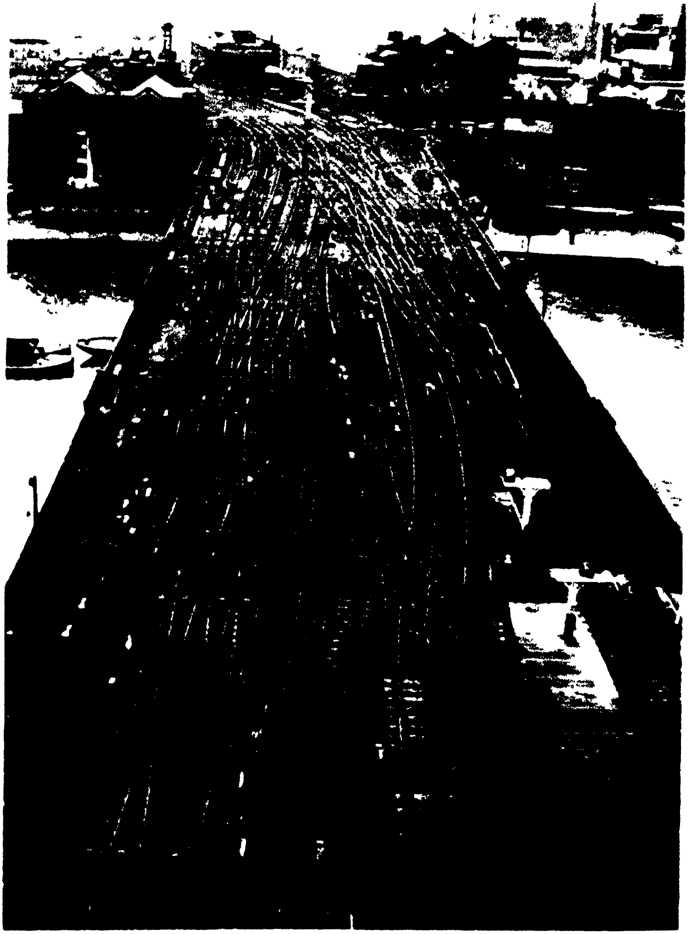
on great inverted bowls of cast-iron, known as "pots," kept at the right distance from each other by wrought-iron or steel tie-bars. On railways in the Tropics and other parts of the world, where the use of a timber sleeper is impossible, because of the partiality of the destructive white ant for this kind of diet, steel sleepers are employed. These are pressed from thin steel-plate into the shape of a pea-pod, inverted so that it may grip the ballast, and with clips pressed out on the top, into which the flanges of the flat-bottomed rails may be securely keyed. Neither of these two types is suitable for our own country; it is doubtful if the "pot" sleeper would stand up successfully to our fast and heavy traffic, and the thin steel sleeper corrodes too soon under the influence of our moist climate. At the end of 1928, however, an order for 70,000 steel sleepers of a more substantial type, sufficient for relaying 35 miles of line, was placed by the Southern Railway, and this may foreshadow an important change in the future type of British sleeper. No really successful concrete railway sleeper has yet been evolved proof against the tendency to crack under the constant vibration.

Ballast forms the support of the railway track. The earliest tracks were simply laid upon the prepared earth formation, and ballasted with soil, but it was soon found that this did not allow sufficiently for the all-important matter of drainage. So gravel ballast was tried, and then cinder ballast, and to a certain extent these may be found still, in various parts of our lines; but the former is not altogether the best medium for drainage, nor is it too readily obtainable, while the latter is dirty, getting in dry weather into the carriages, and, worse still, into the motion of the engines. So gravel and cinders gave way largely to crushed granite, until an equally efficient and very far cheaper substitute was found in the shape of blast-furnace

slag. So useful is this material being found, not only for railway ballast, but for road metal as well, that all over the country the vast mountains of slag which have been tipped as refuse, during years of iron smelting, disfiguring the country in all our iron-working districts, are now being by degrees broken up and put to use. More broken slag is now used for railway ballast than any other material.

Few readers will have failed to notice, at some time or other, the operations of track renewal in progress. The forms of renewal are various; sometimes, and especially where the traffic is heavy, and the rails wear away very rapidly, only the rails are replaced, which is known as "re-railing"; occasionally the fish-plates only are renewed, called "re-plating"; old and dirty ballast is at times exchanged for new, which generally means that the track is lifted somewhat at the same time, and this is variously termed "re-ballasting" or "lifting"; partial or entire "re-sleepering" takes place at intervals; and the commonest of all the operations—that of renewing the track in its entirety—is known as "relaying."

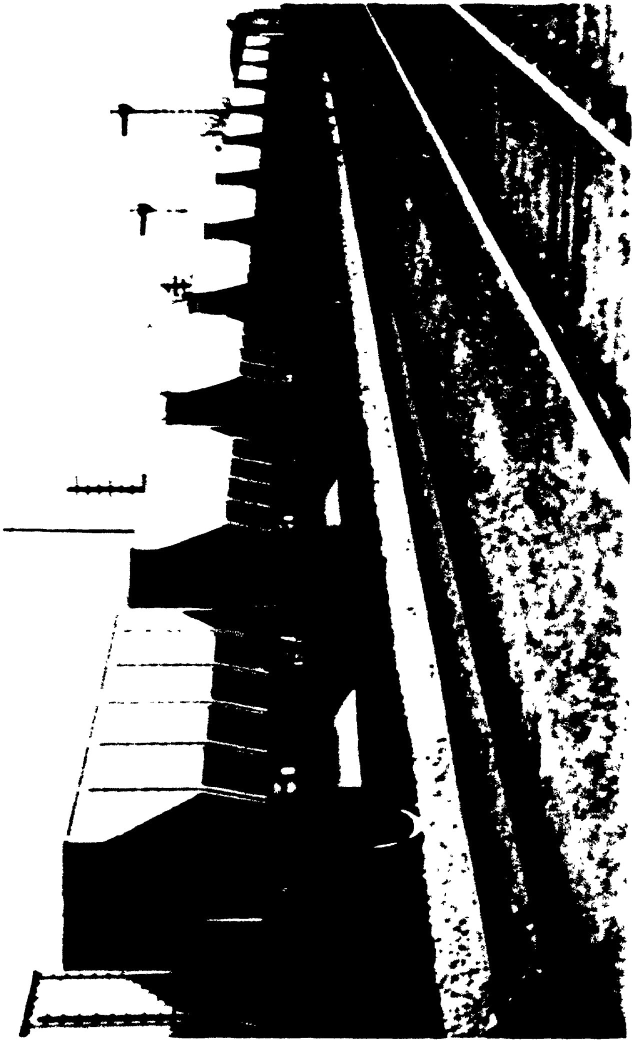
For the work of track renewals special gangs of men are employed. The first operation is that of transporting to the site the necessary materials; if the line is a busy one, the material train will be sent out on a Sunday, in order that a minimum of disturbance to traffic may occur. Rails, chaired sleepers and fastenings are dropped as nearly in their correct positions as possible. The next job is to shovel the old ballast away from the existing track, and it now becomes necessary to impose a limit on the speed of the trains passing over the track that is being renewed, usually of 15 miles an hour. A special indication, consisting of a "C" (for "Commences") in black on white opal glass, illuminated from behind at night, is erected just where the work begins, and a corresponding "T"



P. 5) [illegible] 94

A notable Track Lay-out (p. 100)

The app[illegible] to Cannon St. Terminus, Southern Rly. Two sets of [illegible] and [illegible] is seen in left foreground; note [illegible] also [illegible] electric equipment and electric light signalling



(for " Terminates "), at the end of the stretch of line, shows engine-drivers where they may resume running at normal speed. In order that the drivers of fast trains may get timely warning that they are nearing the point of speed reduction, a third sign is erected half-mile away, consisting of a horizontal green board, fish-tailed at the left-hand end and pointed at the right-hand, illuminated at night with a pair of lamps, green and white, side by side. These indications are illustrated in Fig. 12. Warning

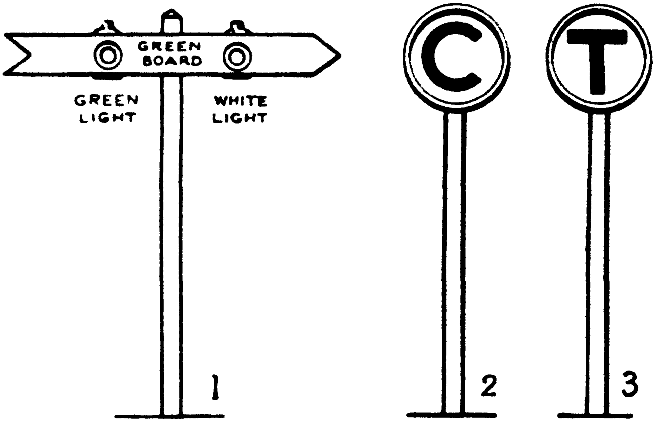


FIG. 12.—" Reduce Speed " Indications for Drivers.
1.—Reduce Speed. 2.—Work Commences. 3.—Work Terminates: Resume Normal Speed.

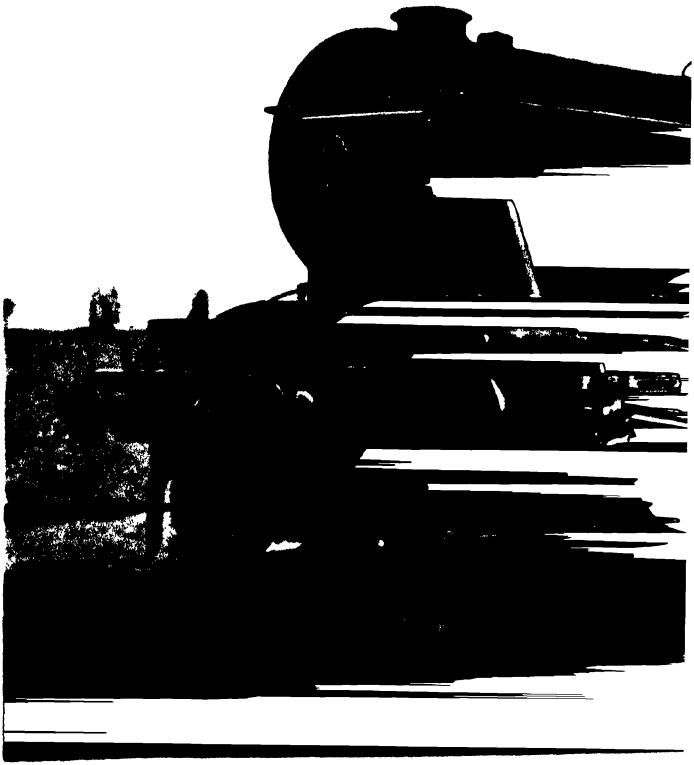
is also frequently given by means of detonators on the line.

When all is in readiness, arrangements are made for the relaying gang to have " complete possession " of the track which is to be renewed, traffic being meanwhile worked over the other track (where the line is double) between the two nearest adjacent signal-boxes. This also must be done on

a Sunday, or, on very busy lines, during Saturday night and early Sunday morning. Time is everything; no time is wasted in unscrewing old fish-bolts, but the heads are knocked off and the fish-plates removed; chair-keys are knocked out; the old rails are lifted out and the old chaired sleepers dragged clear. In go the new sleepers; the new rails are dropped into position; fish-plates are added and fish-bolts are screwed up; and then comes the task of drawing the track exactly into line. Appliances of various sorts are pressed into service, in order to hurry on the work; and when at last the rails are properly "lined," possession of the road is given up, and the running of trains is resumed.

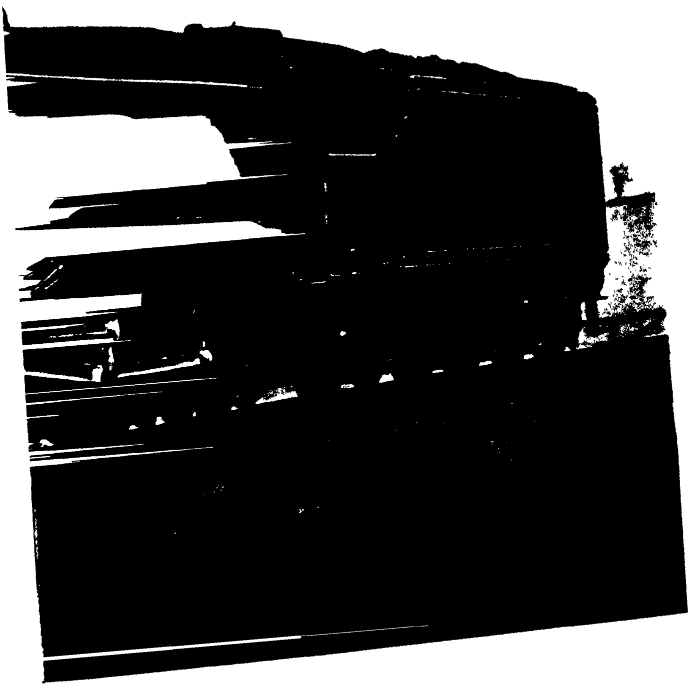
But reduced speeds are still the order of the day, for much work has yet to be done. The next operation is for the ballast train to come and spread new ballast throughout the length of the re-laid track. Modern ballast trains (Plate 51) are composed of "hopper" wagons, tapered inwards inside, and provided with bottom doors which drop the ballast straight on to the track; and another part of the equipment is a special brake-van, under which two large ploughs, whose position is adjustable, spread the ballast evenly over the line as the ballast train moves forward. Then comes the laborious job of "packing" the road, which means forcing the ballast tightly under the sleepers until the surface of the rails is perfectly level, and each sleeper is firmly supported. Careful packing is most important; more than anything else, save the way in which the vehicles themselves are sprung, it influences the smoothness of riding; and it has a good deal to do, too, with the cost of maintaining the line in good order.

Needless to say, complete track renewal is an expensive job. First of all, the enormous quantities of material required to relay one mile of single line require to be men-



Pl. 52

2-Cylinder 4-6-2 ("Pacific") Type Express Locomotive No. 4-76, "Ro



tioned ; the figures now given relate to main line track, laid with 95 lb. British Standard rails :

Rails, each 45 ft. long	235	(149 tons)
Chairs	4,230	(87 „)
Fish-plates	470	(3½ „)
Fish-bolts	940	(¾ „)
Chair-Screws	12,690	(8¾ „)
Wooden Screw Ferrules ..	12,690	—
Wooden Keys	4,230	—
Sleepers	2,115	—

To these figures must be added the cost of the ballast, of which 3,500 tons in all are needed for every mile of double line, and, most important of all, the labour—both of stripping and removing the old track and of laying in the new, and all, as far as possible, without interruption of the running of the trains—so that complete renewal of one mile of single main line track at the present time costs something in the neighbourhood of four thousand pounds.

In the most up-to-date methods of track-laying and track renewal, machinery is pressed into service. Track-laying machines have been in use in America for a number of years past, and, more recently, have appeared on the Great Southern Railway of Ireland and the London and North Eastern Railway in England. When the track-layer is in use, complete sections of track of the standard length—45 ft. or 60 ft., as the case may be—are assembled, with their sleepers and chairs and both rails of each section keyed in position at the materials depôt. These sections are then stacked, five or six at a time, on specially-equipped wagons, which are run with the track-layer to the site of operations. The track-layer itself has a cantilevered arm, of lattice steel construction, extending well forward over the track which is to be relaid ; one by one it lifts the sections of the old track off the ballast, and passes them back by a conveyor arrangement on to the wagons behind

for removal, while at the same time a trolley, so designed that it can move on rails along the whole length of the materials train, is bringing forward a new track section to replace the old. The track-layer then advances over each new section as it is laid. When 60 ft. track sections are being laid, the Morris track-layer (Plate 54) is capable of relaying at a speed of 240 yards to the hour, and the reductions both in the time of relaying and in the cost of labour are very considerable.

No reference has yet been made to the even more costly parts of the track—the switches and crossings. Switches divert the trains from one line of rails to another, and crossings allow one track or one rail to cross another. Both must be the subject of very careful design, in order that the wheels may pass smoothly and easily through. Switches consist of two movable "tongues," which are rails planed down at one end to fine knife-edges (Plate 171). The back ends of these tongues are usually keyed tightly in chairs, and the spring in the rails allows of the planed ends being moved to and fro, according to the direction in which the train is to run. The problem in crossing construction is to allow for the passage of the wheel-flanges, which makes it necessary to leave a gap between the rails, over which the wheels must travel. There is no actual "jump," as, owing to the width of the wheel tyres, which is greater than the width of the rail-head, the tyre is always supported on one rail or the other. Fig. 13 illustrates the method of constructing the "acute," or most common form of rail-crossing; it shows how the "point" and "splice" rails are firmly secured together, and planed down to a fine point, or "nose," and how the two wing rails are bent round in such a way as to form "check" rails for the wheel-flanges, guiding them smoothly through the crossing.

An acute crossing must be used behind every switch

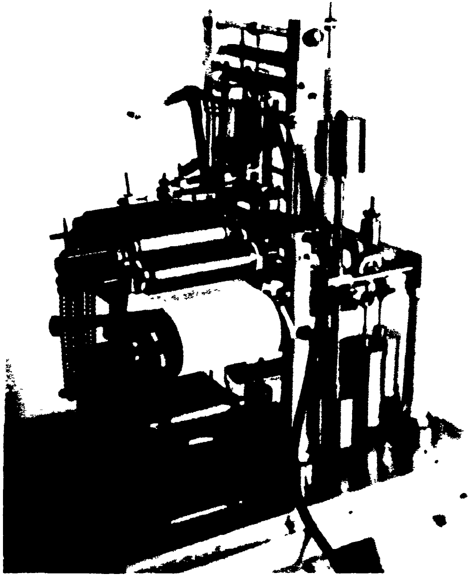


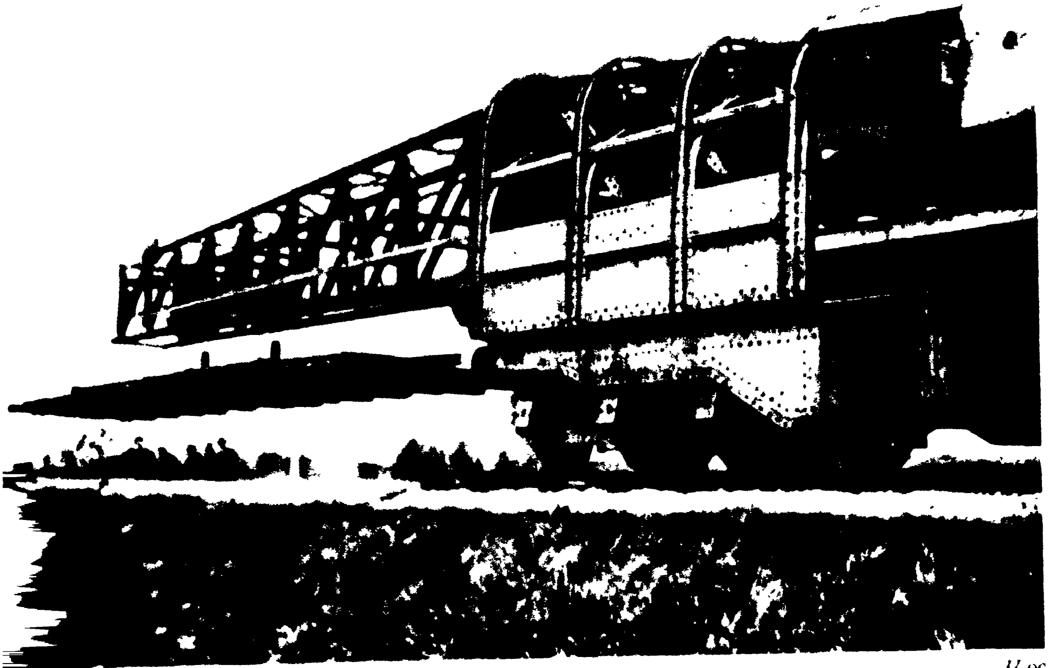
Fig. 53

The Hallade Instrument

Fig. 54

Method of Use in Compartment

The Hallade Train Recorder, for the Graphic Representation of Train Oscillations (p. 100)



but the other form of crossing—the "obtuse"—is only used in diamond crossings (Fig. 13), where one track crosses another. The running over diamond crossings is greatly improved by the use of "movable" diamonds, which can be moved in such a way as to give an unbroken path for the wheels throughout the crossing; the Great Western Railway have laid in this type of crossing at many of their most important junctions, a fine recent example, at Old Oak Common West Junction, appearing in Plate 55. A certain amount of use is made of spring

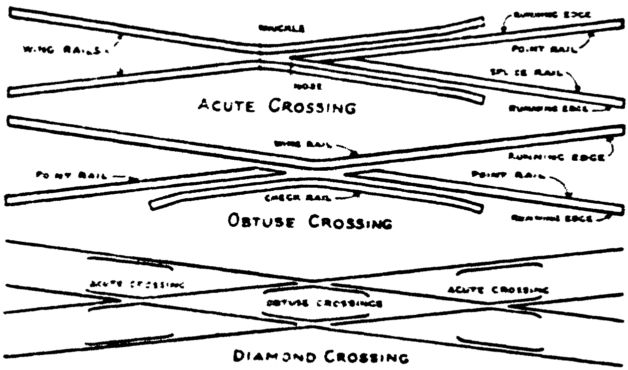


FIG. 13.—Construction of Rail Crossings.

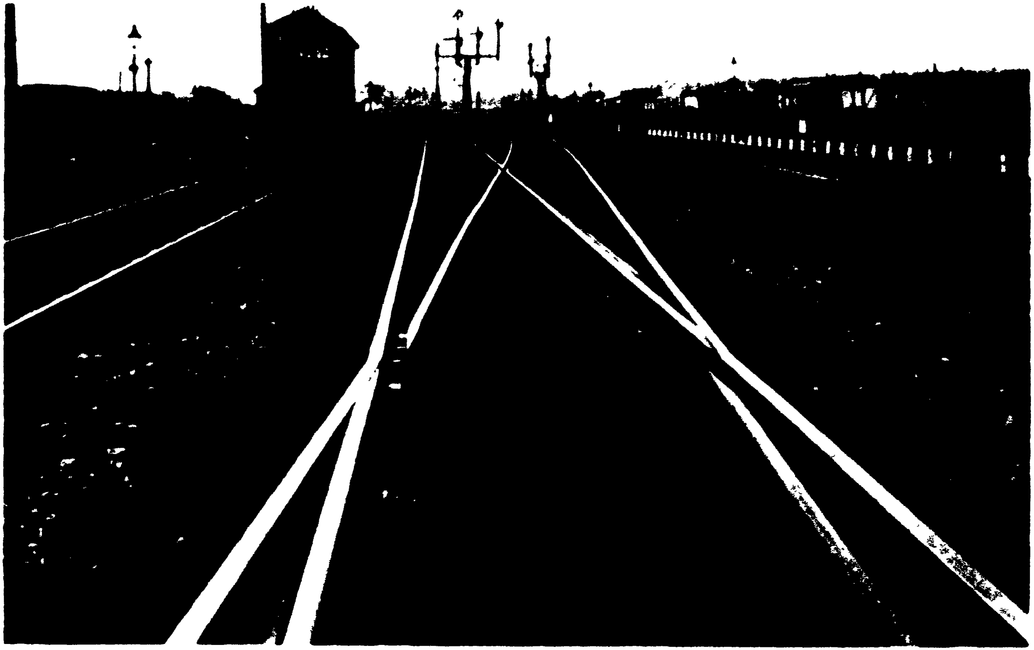
acute crossings also, especially in America, for the same purpose. Then there are more complicated forms of crossing, such as "slip" roads, which are diamond crossings incorporating within their length connections from one of the crossing lines to the other; a "single slip" has a connection of this kind in one direction only, and a "double slip" in both directions. A "cross-over road" allows of passage from one to another of two parallel roads, and a double, or "scissors" cross-over, is a two-way

connection of the same kind. Where such double connections are required, however, a couple of single cross-overs, end to end, are much preferred, if there is room for them, to the scissors cross-over, as the latter is a very complicated and costly item to lay and maintain. A very fine example of modern track-work, outside the Southern Railway terminus at Cannon Street, is illustrated in Plate 50.

And now, lastly, a word or two as to the care of the track. It may surprise many readers to know that every yard of passenger running lines is "walked" daily by the platelayers, in order that they may see that everything is in perfect order. The railway is divided up into sections, each in charge of a "ganger," who has under him the requisite number of "platelayers," and their duty is to see to the maintenance of the track in good order and to keeping it neat and tidy. Defects in track maintenance are to-day made apparent by the use of the French Hallade track recording machine (Plate 53). This portable apparatus, weighing 68 lb., is carried by qualified observers in the train, and by a system of damped pendulums operating pointers inscribes on a moving roll a continuous record of the oscillations on the journey. By this graph weak points in the lining and packing of the track are readily located. The care of track equipped with third and fourth rails for electric traction requires the use of specially insulated platelayers' tools, as seen in Plate 58. On tube railways the men's work can only be carried out at night, when the train service is suspended. Over the gangers come "sub-inspectors" and "inspectors," and so on up to the Divisional or District Engineers, who are responsible to the Chief Engineer of the railway for the large areas of each system that come under their control.

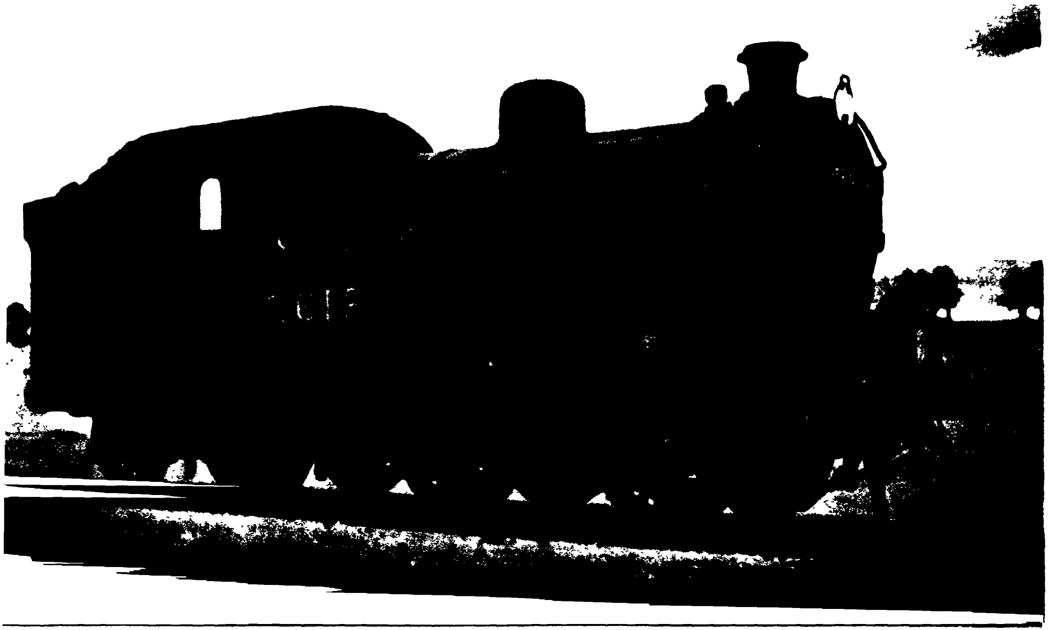
PART II

THE MOTIVE POWER



Pl. 55

Movable Diamond Crossings, Old Oak Common West Junction, G.W.R.



0-6-2 Suburban Tank Locomotive, London & North Eastern Rly. (pp. 114, 115, 163).

CHAPTER VI

The Steam Locomotive—Types and Classes

OF all the factors which together make up the vast and complex organism that we call the railway, it is undoubtedly the steam locomotive that appeals the most strongly. Few, even of those whose general interes in railways is of the most slender kind, can resist the fascination of the locomotive. British railways, by their unremitting attention to details which many engineers regard as of minor importance—to grace of outline, to brightness of livery, and to elegance of finish—have done much to foster this attraction. The naming of locomotives, again, is a further concession to public interest, and so far from being a valueless proceeding, it becomes, when carried out on systematic lines—as, for example, on the Great Western Railway—a useful method of identifying the particular type or class to which an engine belongs. In this connection it is striking to note that the Americans, whose locomotives, for years past, have been distinguished by the clumsiest of outlines, marred still further by masses of external parts and a thick coating of grime above all, have realized the value of public interest in locomotives sufficiently to pay close attention, in their latest express types, to the stowage out of sight of all piping and other details whose presence outside the engine is not necessary, and to the use of attractive coats of colour, daily kept in good condition.

We have little space to spare, however, on the appeal of the steam locomotive; our concern is with the why and

the wherefore of its design and the method of its working. In contradistinction to the electric locomotive, which draws its supplies of power from a centrally-situated power-station delivering its current to the line, the locomotive is a self-contained power-house. The engine itself consists of three parts. There is, first, the boiler in which the fuel is burned, supplying the necessary heat for the generation of steam. There is then the engine proper, consisting of the cylinders and motion, which transmute the energy of the steam into mechanical work. Last of all, there is the undercarriage, into which the cylinders and motion are built, while at the same time it supports the boiler; this carriage serves to transmit the tractive force developed by the driving-wheels to the "draw-bar" connecting engine and train. Attached to the engine is the tender, which serves to carry the supplies of coal and water needed for the journey.

The separate tender is not always a necessary adjunct, and in the case of the "tank" engine it is dispensed with. Tank locomotives are a characteristic product of the short-journey travelling conditions of Great Britain, and no other country in the world uses this type of engine to the same extent that we do here; in fact, no less than 40 per cent. of the total locomotive stock of this country is of tank types. The *raison d'être* of the tank engine is the waste of hauling power involved in dragging about a heavy tender, containing supplies far more ample in quantity than the length of journey requires. Tank locomotives, therefore, carry their limited supplies of coal and water on their own main frames, and the engine itself is coupled directly to its train without the interposition of a tender. A typical suburban tank locomotive appears in Plate 56. A small "bunker" behind the cab suffices to hold from 2 to 4 tons of coal, and from 1,000 to 2,000 (or in the biggest

engines up to 2,500) gallons of water are housed in long flat side-tanks on both sides of the boiler, connected by piping underneath the boiler which ensures that the water is maintained at the same level in both tanks, so that the engine does not lose its balance about the centre-line. These quantities average rather less than one-half those carried in a large modern tender. Occasionally the water is contained in a "saddle"-tank, or a "pannier"-tank, which rests on the top of the boiler, but this position is seldom favoured in modern designs, except in the case of shunting engines. Additional, or, in some cases, alternative water-space is arranged at times under the coal-bunker, in the form of a "well"-tank.

There are other advantages connected with the use of tank engines. They are designed to have a good look-out from the cab in rear as well as in front, in order to be adapted for running as well with the coal-bunker leading as chimney first. This means that, on the short-distance suburban services round London and other large cities, as well as on short country services, it is not necessary to turn the engines on turn-tables at the end of each trip, but the outward trip is made with the engine chimney leading, and the return trip with the bunker first. Both time and trouble are thereby economized at the terminal stations. Main line engines are occasionally run with the tender in front, but it is not advisable, as a poor look-out ahead is obtained over a big tender piled high with coal.

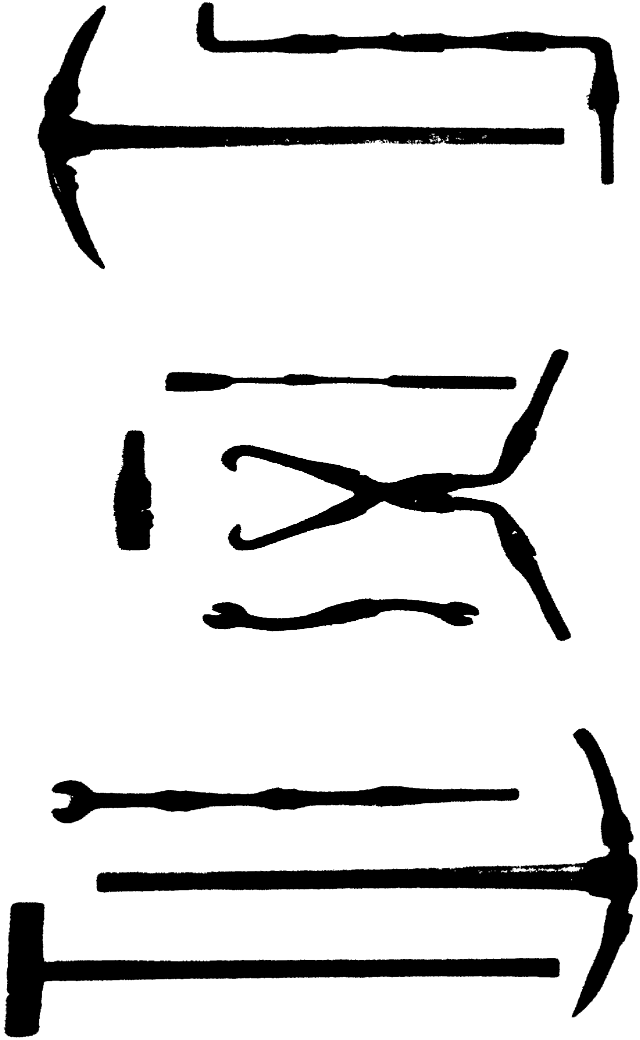
Apart from suburban services, of recent years considerable use has been made in this country of tank engines for short distance express services. British railways have a certain number of "express tank" types (Plate 59), which are express engines in every feature of their design other than the use of a separate tender storage for coal and water. The largest 4-6-4 express tank locomotives of the Southern

(the Brighton "Charles C. Macrae" design) and L.M.S. (Lancashire and Yorkshire, Glasgow and South Western and Furness designs) are extremely powerful machines of roughly 100 tons' weight apiece. For many years the principal services of the Brighton line were worked by tank engines, including the 60-minute Victoria-Brighton journey of 51 miles, the Victoria-Eastbourne run of 65¾ miles, and others, but the present tendency is to replace the 4-6-4 and 4-4-2 tank locomotives on these services with 4-6-0 tender engines of the "King Arthur" type. There is always, however, the advantage of economy in deadweight when a tank engine is used in preference to a tender locomotive; conversely, it must be remembered that the increased weight of the tank as compared with the tender engine imposes a greater limitation of size and power in the former case than in the latter. It may be added that express tank engines, when running on fast passenger services, are almost invariably worked chimney first, in order that the driver may have all his operating mechanism in front of him, especially when running at speed. The latest 4-8-4 passenger tank locomotives of the French P.L.M. Railway, however, have their chief controls duplicated at the back of the cab, to overcome the difficulty last mentioned when the engines are working bunker first.

We come next to what is, perhaps, the most important of all the features of locomotive design. The work that a locomotive is called upon to perform is governed chiefly by the arrangement of its wheels, and, in particular, by the number and the size of its coupled wheels It is well, therefore, to consider the wheel arrangement of the locomotive before we devote attention to any other part of its internal economy. For ready description of this wheel arrangement, a simple numerical notation has been devised, and as we shall have constant occasion

P 57

2-6-0 ("Mogul") Mixed Traffic Locomotive, Southern Rly.



to make use of it—and have, indeed, done so already in the last paragraph—a brief explanation is necessary.

The wheels supporting a locomotive are of two kinds. There are, first of all, " idle " wheels, which have no function beyond that of helping to distribute the weight of the engine evenly over the tracks. And then there are the " coupled " wheels, which comprise the driving wheels proper, and one or more pairs of wheels of the same diameter, connected to the driving wheels by means of coupling rods, which ensure that the whole of the coupled wheels move in unison. The notation referred to consists of three figures, the middle one of which indicates the number of coupled wheels, and the first and third of which show the idle wheels in front of, and behind, the coupled wheels respectively. If there are no idle wheels behind the coupled wheels, the last pair of the latter being located under the driver's cab, a cipher must be used in the notation accordingly ; similarly, if the leading pair of engine wheels are coupled, the first figure of the notation is " o."

To take a well-known example, the London and North-Eastern " Pacific " express engines of the " Flying Scotsman " type (Plate 52), with four idle wheels carrying the leading end of the engine, six coupled wheels, and another pair of idle wheels under the cab, are of the " 4–6–2 " type. The new " Kings " (Plate 66) and the various groups of " Star " and " Saint " class express engines on the Great Western, the London, Midland and Scottish " Royal Scots " (Plate 101) and " Claughtons," and the Southern " Lord Nelson " (Plate 75) and " King Arthur " (Plate 92) engines are similar to the " Pacifics " save for having no idle wheels at the rear end of the engine ; their notation is therefore " 4–6–0." In the " Mogul " type locomotives (Plate 57), which are now in such widespread use by all the four British groups for " mixed traffic " service—

that is, excursion and other medium-speed passenger trains and express goods work—the leading bogie of the express engines is exchanged for a single pair of leading wheels; they are described by the figures "2–6–0."

And then there is the vast assortment of freight engines which have the whole of their four or three axles coupled together, but no idle wheels at either the leading or the trailing end; their notations are respectively "0–8–0" and "0–6–0." On the Continent the description goes more logically by axles rather than by wheels, and our "4–6–2" type there becomes the "2–3–1" type. On certain French lines, like the Etat, this notation becomes part of the engine number, such a number as "231.654" indicating, not that the railway concerned possesses nearly a quarter of a million locomotives, but "No. 654 of the 2–3–1 type." On other French lines, such as the Nord, the serial number of the engine is preceded by a number indicative of the coupled axles, "3.1216," indicating No. 1216 of the three-axles or six-wheels coupled type. In Germany a letter replaces the middle figure of the notation, "B" signifying four wheels coupled, "C" six wheels coupled, "D" eight wheels coupled, and so on. The various locomotive wheel arrangements in use are set out in tabular form in Appendix E, under the different notations.

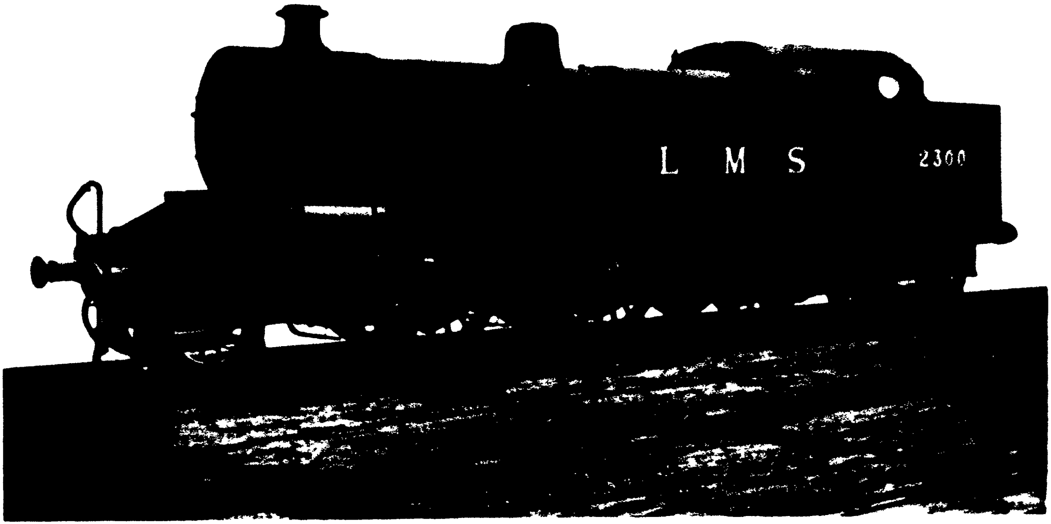
The most important part of the locomotive notation is obviously its central figure. There is, however, a certain degree of importance in the leading figure, as indicating the front-end design of the engine, and therefore its suitability or the reverse for fast travelling. Here the use of the figure "4" invariably indicates the provision of a "leading bogie"—that is, a small four-wheeled truck pivoted in the centre under the front end of the engine, and so arranged as to have a limited amount of side play, its central position being restored, after the passage of a curve, by means

of a system of springs and swinging links. By its freedom to swing, the bogie gives flexibility to the engine wheelbase, and allows of the smooth traversing at speed of the curves in the road. The figure "2" may be taken, generally, as implying the use of a two-wheeled "pony truck" at the front end, pivoted to the main frames at a point in rear of the axle concerned, and most of the modern engines so equipped, such as the "Moguls" mentioned on page 107, may be driven at fairly high speeds without risk. Except in the case of tank engines, the figure "4" is of rare occurrence behind the coupled wheels, a bogie under the firebox being unknown in the case of a British tender engine. But it is coming into use in some of the latest American designs, such as the Canadian National 4–8–4 "Confederation" class (Plate 19), and the high-speed "Hudson" 4–6–4 passenger type (Plate 111) of the New York Central Lines. A single pair of idle wheels under the firebox of a tender engine is not so unusual; it is provided in cases where greater lateral development of the firebox is desired than can be obtained when that expansion is obstructed by the presence of large coupled wheels. The most common examples of locomotives with this trailing pair of idle wheels are the 2–6–2 ("Prairie"), 4–6–2 ("Pacific"), 2–8–2 ("Mikado") and 4–8–2 ("Mountain") wheel arrangements. These nicknames, by the way, are mostly of American origin.

We now come to the coupled wheels. In the early days of the steam locomotive, doubt was expressed by some of the pioneers as to whether sufficient adhesion could be obtained by the bearing of the tread of a smooth driving-wheel tyre on a smooth rail. As mentioned in Chapter I, Blenkinsop, one of the earliest of locomotive builders, attempted to get over the difficulty by the use of a toothed driving wheel engaging in a rack, thus foreshadowing the

funicular railways of to-day, on which the steepness of the gradients compels rack-and-pinion propulsion. It was soon discovered that no such adventitious aids were required in the case of locomotives designed to travel over reasonably level tracks. But at the same time it was realized that, if power adequate to the needs of the traffic was to be transmitted from the driving wheels to the rail, without loading those wheels to such an extent as to damage the track, more than one pair of driving wheels would be necessary.

As far back as 1825, therefore, we find in "Locomotion No. 1" of the Stockton and Darlington Railway a locomotive with four wheels coupled, and only two years later the "Royal George" was designed, incorporating three coupled axles, or six-coupled wheels. The effect of coupling these axles was not merely to make their wheels move in unison, but to render the total weight of the engine available for "adhesion." That is to say, instead of the "grip" of the driving-wheels on the rails being governed only by the weight coming down on the driving axle proper, that part of the engine weight coming down on the other coupled wheels was made available for adhesion It was imagined in earlier days that the coupling of axles would prove a considerable deterrent to speed, and for that reason, so soon as railway permanent way was sufficiently improved to carry heavier axle-loads, the "single-driver" engine (Plate 8) came into vogue, and remained popular for express passenger work down to the end of last century. But as increased traffic demands have entailed the provision of larger locomotive boilers and cylinders, so the coupling together of wheels has had to keep pace with the call for enhanced adhesion weight, in order that this increased tractive power may be transmitted to the rail. In this way, passenger locomotive types have proceeded from four-wheels-coupled to six-coupled and even—in the latest Continental and American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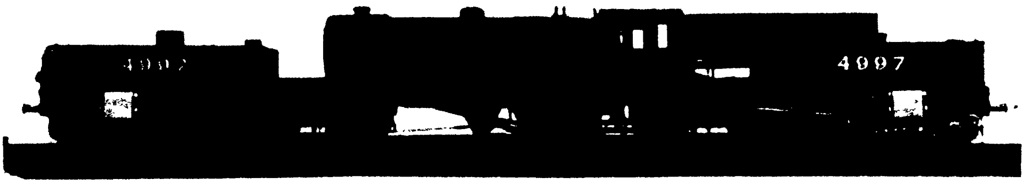
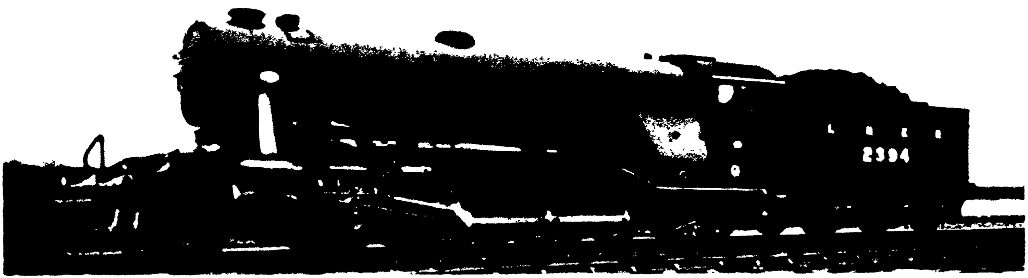


[illegible] Garratt [illegible] L. M. S. Rly. (pp. 117, 118)



[illegible] Mikado type [illegible] wheels, L. N. E. R. (pp. 114, 164).

British Locomotives for Heavy Freight Service.

practice—eight-coupled types (Plate 62), while the graceful old "single-driver" passenger engines of days gone by, no longer equal to modern conditions, have practically vanished altogether. In freight working we are no longer content merely with six-coupled wheels; eight-coupled engines are very common, while in other countries ten-coupled wheels, and, very occasionally, twelve-coupled wheels (Plate 62), are met with. The only ten-wheels coupled locomotive now in use in England is the heavy 4-cylinder 0–10–0 banking engine used by the L.M.S. Company for assisting trains up the 1 in 37·7 grade of the Lickey incline, between Cheltenham and Birmingham.

That the coupling of axles together, in the case of passenger engines, has any hampering effect on speed is amply disproved by the fact that the writer's own highest speed record—one of 91·8 miles per hour—was made by a six-coupled locomotive; the train was a Great Western Birmingham express, negotiating the moderately steep falling gradient (1 in 187) from Southam Road to Leamington. Again, the eight-coupled 2–8–0 "mixed traffic" engines of the same company have been timed at speeds of over 60 miles per hour, while the latest 4–8–2 express engines of the Est and P.L.M. Railways of France have both been authentically timed at speeds of over 70 miles per hour. In brief, while there is probably a slight loss of power entailed by the whirling round of coupling rods at high speed, the loss is so small, provided that they are properly "balanced" as to be negligible. It may be added that the maximum axle-loading allowed on British railways was, up till recently, 20 tons, or 10 tons per wheel. In the latest British express passenger designs, however—such as the G.W.R. "King George V" and the L.N.E.R. "Enterprise"—this figure has been advanced to 22½ tons, giving a total of 67½ and 66½ tons adhesion

weight respectively, on six-coupled wheels. In America axle-loading up to 30 tons is not unknown, but over Continental tracks no greater loading than about 18 tons, or 9 tons per wheel, is encouraged.

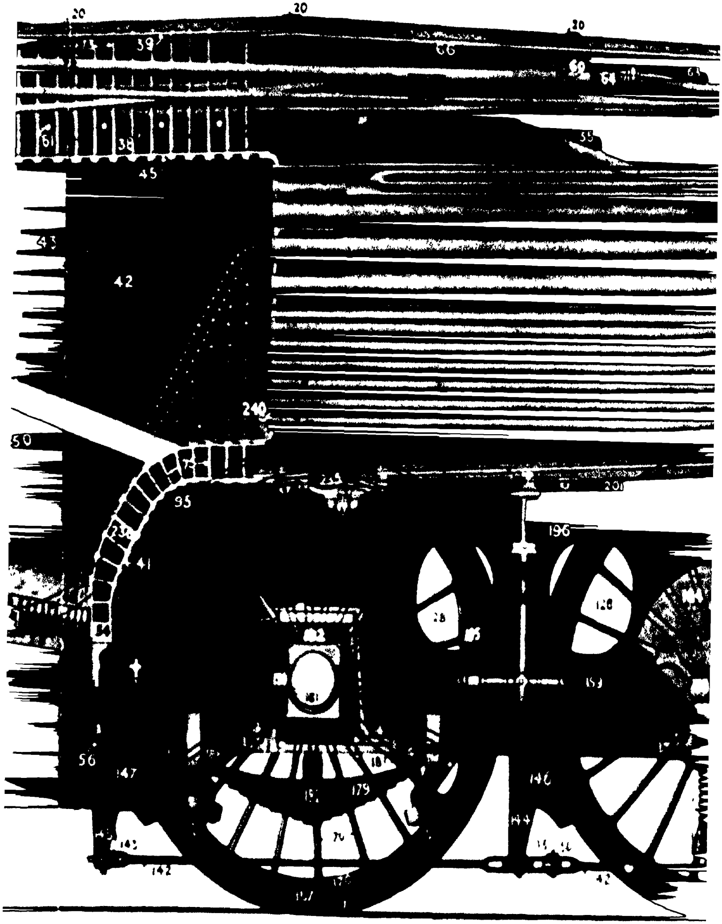
A much more important influence on both speed and tractive power is embodied in the diameter of the driving wheels. A smaller diameter increases the tractive effort of a locomotive, while a larger diameter reduces it; on the other hand, a uniform piston speed in the locomotive cylinder results in a lower rate of travel in the case of the small-wheeled engine than in that of the large-wheeled engine. Consequently, the freight engine, which is required to haul heavy loads at moderate speeds, is provided with driving wheels of about 4 ft. 6 in. to 5 ft. in diameter, and all, or nearly all the wheels are coupled together, in order that the maximum possible proportion of the engine weight may be available for adhesion. The express engine, on the other hand, requires driving wheels of between 6 ft. 3 in. and 6 ft. 9 in. diameter, which are suitable for the highest speeds normally run, and, as previously mentioned, a certain proportion of its weight must be carried by a leading bogie, with a view to the smooth negotiation of curves. The "mixed traffic" engines previously described are tolerably well fitted for every kind of duty, with driving wheels of a diameter intermediate between those just mentioned, from 5 ft. 6 in. to 5 ft. 8 in. being the customary figure. Suburban tank locomotives, which require considerable powers of acceleration between stops, but no particularly high speeds, are generally fitted with driving wheels of about 4 ft. 9 in. to 5 ft.

A few words are now necessary as to the locomotives in general use for the varying duties of the railway. Here heavy express passenger work is usually entrusted to 4–6–0 engines (Plates 66, 75, 101), except on the L.N.E.R., where

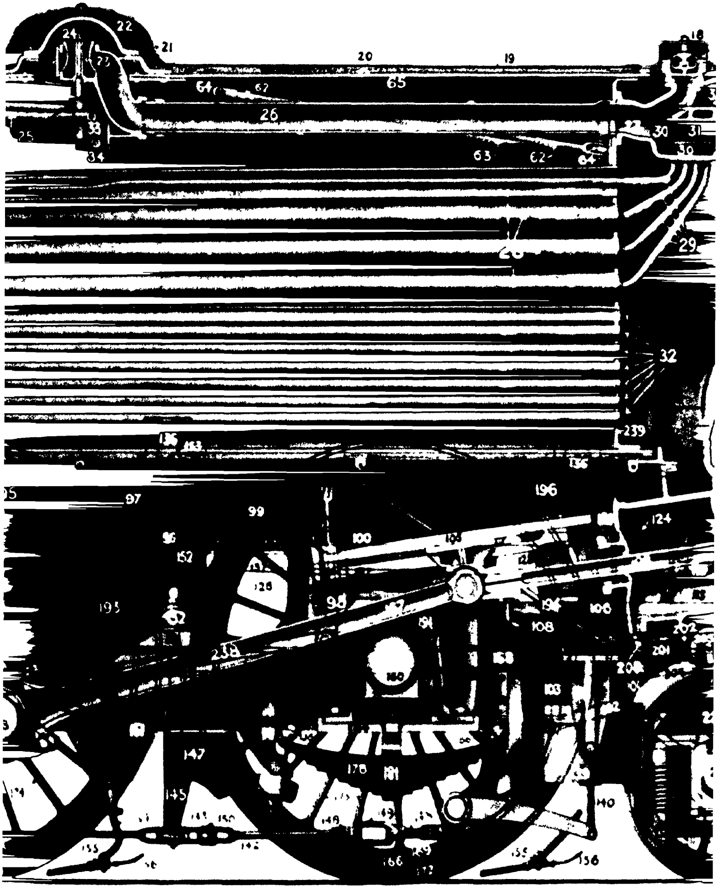
4-6-2 THREE CYLINDER "PACIFIC" EXPRESS LOCOMOTIVE, L.N.E.R.

KEY TO NUMBERED PARTS ON PLATE 61.

1. Chimney.
2. Chimney Liner.
3. Chimney Petticoat.
4. Lamp Iron.
5. Hand Rail.
6. Smokebox Door Handles.
7. Smokebox Door.
8. Dart for Fastening Smokebox Door.
9. Smokebox Door Baffle Plate.
10. Smokebox.
11. Ring Blower.
12. Blast Nozzle.
13. Exhaust Pipe.
14. Exhaust from Outside Cylinder.
15. Exhaust from Inside Cylinder.
16. Steam Pipe to Outside Cylinder, Superheated.
17. Steam Pipe to Inside Cylinder, Superheated.
18. Anti-Vacuum Valve.
19. Boiler Lagging Plate.
20. Boiler Lagging Band.
21. Dome Casing.
22. Dome.
23. Regulator Valve.
24. Steam Pipe Head.
25. Regulator Rod.
26. Main Steam Pipe to Header.
27. Superheater Header.
28. Superheater Flue Tubes.
29. Superheater Elements.
30. Receiving Passage for Saturated Steam.
31. Discharge Chambers for Superheated Steam.
32. Flue Tubes.
33. Regulator Rod Bell Crank.
34. Regulator Bracket.
35. Injector Pipe.
36. Pop Safety Valve.
37. Pop Safety Valve Section.
38. Washout Plugs.
39. Outer Firebox Wrapper Plate.
40. Outer Firebox Back Plate.
41. Outer Firebox Throat.
42. Firebox.
43. Inner Firebox Side Plate.
44. Inner Firebox Back Plate.
45. Inner Firebox Crown Plate.
46. Firebars.
47. Firebars Carrier.
48. Firebars for Drop Grate.
49. Drop Grate S[illegible] Bracket.
50. Firebrick Arch.
51. Fire Hole.
52. Firehole Door.
53. Deflector Plate.
54. Foundation Ring.
55. Ashpan.
56. Ashpan Damper.
57. Ashpan S[illegible].
58. Firebox Side Stays.
59. Boiler Diagonal Stay Rod.
60. Stay Rod Brackets.
61. Firebox Cross Stays.
62. Smokebox Tubeplate Diagonal Stay Rod.



...n of 3-cylinder 4-6-2 ("Pacific") Express
FLYING SCOTSMAN TYPE [illegible]
A key to all the numbers [illegible]



tive, London & North Eastern Railway pp. 123, 132, 138, 140)
H. N. GRESLEY, CHIEF MECHANICAL ENGINEER, L.N.E.R.
is given on the back of the diagram

4–6–2 (" Pacific ") locomotives are now in use to a total number of 67. On the Continent and in America the latter is of all types the most common for express passenger service, though the 4–8–2 (" Mountain ") wheel arrangement (Plate 62) is now coming into favour for the heaviest duties. For intermediate passenger work the favourite type in Great Britain is the 4–4–0 (Plate 79), of which the total number at work is just under 3,000 (21 per cent. of the total of British tender locomotives) ; on the Midland Division of the L.M.S. system, indeed, where train-loads are expressly kept down to a moderate figure, the main line trains are exclusively hauled by 4–4–0 engines. A variation of the 4–4–0 type, with a trailing pair of idle wheels which converts it to the 4–4–2, or " Atlantic " type (Plate 25), has had some vogue in this country, especially on the lines making up the L.N.E.R., which still owns some 240 engines of this description, and uses them freely on important expresses (Plate 81). A few earlier 2–4–0 passenger engines are still at work, mainly on the L.M.S. system, but the 0–4–2 wheel arrangement, confined chiefly to the late London, Brighton and South Coast Railway—whose famous engine, " Gladstone," is being preserved in York Railway Museum (Plates 7 and 10)—is now virtually extinct.

A " maid-of-all-work " type for freight service in Great Britain is the 0–6–0 (Plate 63), and of both 0–6–0 tender and tank engines there are far more in existence than any other wheel arrangement that could be named. There are roughly 6,400 of the former type and 3,650 of the latter, representing respectively 45 and 40 per cent. of the total number of tender and tank engines in this country. But in the last two decades many 0–8–0 engines have been built, with their later 2–8–0 (Plate 64), or " Consolidation " development. It was the Great Central " Consolidation " design which became standardized by the War Office for

service Overseas during the late war, hundreds of these engines being built ; they have now been absorbed into the locomotive stocks, not only of the parent L.N.E.R., but also, to a more limited extent, in those of the L.M.S. and G.W. Railways. The still larger 2–8–2 or " Mikado " wheel arrangement has, as yet, made its appearance in Great Britain only on the London and North Eastern Railway, which has built two very powerful 3-cylinder 2–8–0 engines (Plate 60), uniform in boiler and general design with the passenger " Pacifics "

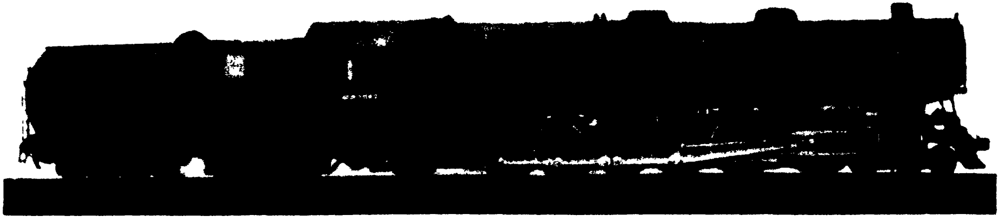
The L.N.E.R. " Mikados " are also of considerable interest in that the nominally " idle " wheels at the cab end have been transformed into useful wheels by the installation of American " booster " equipment. This consists of a small two-cylinder engine, which is cut in when the locomotive is starting or ascending a heavy grade, affording valuable assistance without an excessive drain on the steam supply of the boiler ; then, when the speed reaches 20 or 25 miles an hour, the " booster " is cut out, much in the same way as the operation of a bicycle free-wheel, and the locomotive proceeds, without any frictional resistance from the booster gear, under the power of its three ordinary cylinders. The only drawback of such extremely powerful freight engines as these is that there is difficulty in accommodating in sidings and elsewhere the 100-wagon trains which they are capable of hauling, with the result that their workings have to be confined strictly to certain schedules, planned in such a way as to make it unlikely that there will be any interference in their through runs from starting-point to destination.

British tank locomotives are built in a very large variety of wheel arrangements. For suburban service the most popular of all types in earlier years was probably the 0–4–4, with four-coupled wheels at the leading end of the

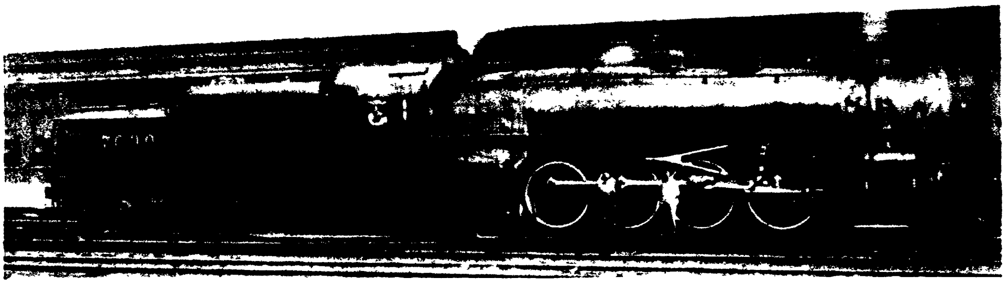
engine and a bogie in rear; another type widely built was the 2–4–2, with radial axles front and rear. The radial axle, it may be explained, is an arrangement whereby adjustment of the engine wheelbase to curves is obtained by a limited sliding action of this axle, in the transverse plane, as compared with the swinging action of the bogie or pony-truck. An expansion of the double-end type last-mentioned, but with bogies front and rear, is the 4–4–4, which was built extensively by the late North Eastern Railway, but not copied elsewhere; by other railways large numbers of 4–4–2 tank engines have been built. Preference in these days is for six-coupled tank engines, owing to the superior advantage that they offer in the matter of adhesion. Chief among the wheel arrangements used is the 0–6–2 (Plate 56), with six-coupled driving wheels and a radial axle supporting the bunker end. More bunker space is offered by the 0–6–4 wheel arrangement, favoured by the Midland Division of the L.M.S., and a still larger engine of this type can be built on the 2–6–4 arrangement of wheels, as in the new standard main line tank class of the L.M.S. Company (Plate 59), or the heavy mineral tanks of the Great Central Section of the L.N.E.R. The Great Western Company favours the 2–6–2 arrangement of wheels, and has constructed many such tank engines, both for suburban and main line use. Larger still is the 4–6–4 tank, to which reference has been made previously, built as an express engine in every respect other than carrying a separate tender, but only a limited number of these engines has been built. For short distance freight work the 0–6–0 type predominates; for heavier mineral service, and especially the laborious task of pushing trains of wagons over the "humps" in marshalling yards, a variety of powerful types is in use, such as the 0–8–2, 2–8–0, 0–8–4 and 4–8–2 wheel arrangements.

In completing our survey of locomotive wheel arrangements, it is necessary briefly to review the way in which locomotive engineers are attempting to deal with the handicap imposed on their designs by the narrow limits of the railway construction gauges, as we have already seen in Chapter III. In the largest locomotives of both our own and other countries, the maximum cross-sectional limits of development have already been reached; and the only further development possible is, therefore, a longitudinal one. In past years such development lengthwise has been necessary, on many lightly-laid railways in the Colonies and elsewhere, in order to spread the weight of a locomotive of reasonable power over as great a length of track as possible, and so to reduce the weight per axle to a low figure. The chief problem, in so increasing the length of a locomotive, is to arrange that it shall be sufficiently "flexible" to traverse the curves in the line; and on the Colonial lines mentioned, many of them of narrow gauge and sharp curvature, this problem has been acute.

It has been solved by the design of various types of "articulated" locomotives. The earliest of these put in service in our own country were the "Fairlie" engines of the Festiniog Railway in North Wales, which has a gauge of only 1 ft. 11½ in., and very sharp curves. In these locomotives the four cylinders are mounted on two four-wheeled *chassis* (with the four wheels coupled in each case) which are both free to swing in the same way as an ordinary bogie. Above the framing of the engine is mounted a double-ended boiler, with chimneys at both ends and one central firebox and cab, the complete unit being operated, of course, by one driver and fireman. The notation of this machine is thus 0–4–4–0, or, more strictly, perhaps, 0–4–0 + 0–4–0. A considerably larger development of the Fairlie engine has been the "Mallet" type of locomotive,



4-12-2 Freight Locomotive for heavy service on Mountain Division (p. 111)



Pl. 62. *Face p. 110.*

4-8-2 ("Mountain" type) express passenger locomotive (p. 113)

Two remarkable Locomotives, Union Pacific Rly., U.S.A.

0-6-0 Standard Freight Locomotive, London, Midland & Scottish Rly. (p. 1[illegible], 2[illegible])

originating in France. Here the same two pivoted *chassis* are employed to carry the engine, but with the cylinders and motion of each *chassis* arranged in tandem fashion, instead of back-to-back, and above this long and flexible mechanism is mounted a boiler of ordinary design and large size. Most of the Mallet designs are compound locomotives, the steam from the boiler doing its work in two high pressure cylinders on the front *chassis*. and then being conducted to two cylinders of larger diameter on the rear *chassis*, for a further stage of expansion. The Mallet principle has had a considerable vogue in America, where engines of enormous size and power have been constructed on these lines, and has also been used to some extent in South Africa (Plate 67).

A further development of the same order is the "Garratt" locomotive (Plates 60 and 67). In this case the same two independent *chassis* are used, but they are located some distance apart, in order to carry between them, on a heavy girder frame which unites them together, a boiler of larger diameter than could be accommodated immediately above the wheels. This is a very important consideration in a country like our own, where the cross-sectional limits of the construction gauge are so exceptionally restricted. Experimental " Garratt " locomotives are already at work in Great Britain. The most noteworthy of them is one which has been built to afford banking assistance to heavy coal trains up a long 1 in 40 incline extending from near Barnsley towards Penistone, on the London and North Eastern Railway. This 178-ton engine—the heaviest and most powerful locomotive of any type at work in the British Isles to-day—is carried by the *chassis* of two 3-cylinder 2-8-0 freight engines, arranged back-to-back; steam is supplied to the six cylinders by a boiler of 7 ft. diameter. Although worked by one crew, this locomotive undertakes

with ease the duties previously performed by two 2-8-0 tender engines. The wheel notation of the L.N.E.R. "Garratt" is 2-8-0 + 0-8-2. The London, Midland, and Scottish Railway also has in service three large 2-6-0 + 0-6-2 "Garratt" engines (Plate 60), which are each hauling coal trains of 85 to 90 wagons over the heavy gradients of the Midland main line between Toton Sidings, near Nottingham, and London. It should be noted that the "Garratt" locomotive carries its supplies of coal and water in front and in rear of the boiler, above the two *chassis*, and thus is, in effect, a tank engine of large size, requiring no separate tender.

Various external indications which may have caused mystification to readers are carried by the engines of different companies. On the London, Midland and Scottish Railway the engine carries the number of the "shed" to which it is attached, Western Division engines usually displaying it in the centre of the cab roof, while Midland Division engines carry it on the smokebox door, above the engine number proper. On the Great Western Railway the sheds are known by code letters, which are usually painted inside the cab. According to their tractive power, locomotives are classified in various groups for traffic purposes, and these classes are sometimes indicated externally; on the L.M.S., for example, the class number is shown in brass figures on the side-sheets of the cab. The power classification on the latter railway runs from "1" in the smallest engines to "6" in the case of the "Royal Scots." Another important grouping of locomotives has relation to their weight, as many of the heavier engines are barred from running over subsidiary lines and branches of their respective railways owing to the existence of underline bridges of insufficient strength to carry them, scanty clearances, sharp curves or other obstacles. On

the Great Western Railway this last-mentioned classification is indicated by letters on the side-sheets of the engine cabs, encircled by discs of various bright colours.

Before we conclude this chapter, it is necessary to refer briefly to the method of ensuring an adequate water supply to locomotives entrusted with the duty of making long non-stop runs. On such a journey as the Great Western 225¾ miles from Paddington to Plymouth, with the normal load of the "Cornish Riviera Express," the engine requires at least 30 tons of water, and often more. Despite the fact that the average locomotive tender is merely a large water-tank, above which is arranged a small space for coal—inclined downwards on top so that the coal may slide readily down towards the fireman's shovel—the capacity of the biggest British tenders does not exceed 5,000 gallons of water, and in the case of many express engines the tender water capacity is only 3,500-4,000 gallons. Further to increase the size would be a wasteful proposition, from the haulage point of view, and arrangements are therefore made for the engine to take up fresh supplies of water, without stopping for the purpose, from track-troughs laid between the rails. The method was first devised by the late John Ramsbottom, in 1859, and tried on the London and North Western Railway, of which he was then the Locomotive Superintendent at Crewe.

For the laying of track-troughs it is necessary to select a stretch of line free from sharp curvature, and, of course, perfectly level. The troughs themselves are about 18 inches wide and 6 inches deep, with their upper surface slightly above the rail-level; the earlier wooden types are now giving place to constructions of sheet steel. A length of just over ¼-mile is found sufficient for the purpose required. Under the tender of the locomotive there is arranged a hinged "scoop," normally lifted well above

rail level. As the train approaches the troughs, whose presence is usually emphasized by large white display boards at the side of the line, the fireman lets down the scoop, its sharp lower edge being now roughly at rail level. At the beginning of the trough the track is lowered for a short distance on a gentle gradient, which has the effect of introducing the cutting edge of the scoop into the water. As the scoop cuts through the water, the speed at which the train is travelling forces the water, under considerable pressure, up a vertical delivery pipe of large diameter and through a curved or a " mushroom " head down into the tender tank. As soon as the tank has been refilled, the scoop must be lifted, and some form of power assistance—either steam or compressed air—is often provided to enable this to be done against the pressure of the water. If the scoop is not lifted in time, a cataract of water will pour out of the top of the tender, and cases have occurred in which nearly the whole of the coal has been washed off the tender in this way. The level of the water in the tender tank is indicated to the crew by a water-gauge on the tender-front.

Elaborate arrangements have to be made to ensure a rapid re-filling of the trough after each locomotive has taken its supply. These include a sensitive ball-valve mechanism in the tank-house at the lineside, from which the water is delivered to the trough at a number of different points. In winter a number of the troughs, especially those in exposed places, have to be kept warm by steam, in order to prevent ice from forming on the surface of the water; elsewhere the trains pass in such rapid succession that this provision is unnecessary. It should be added that the installation of water-troughs is not merely to encourage the running of trains over long distances without intermediate stops; they also enable engines to take water where it is

cheapest, most abundant and of best quality, as well as economizing the time spent at stations is taking water by the ordinary means. On the late Lancashire and Yorkshire Railway—now part of the L.M.S. system—where no daily run was made of much greater length than 50 miles, track-troughs have been installed over every main line of that ramified system, and practically every type of engine—tender and tank alike—is equipped with the pick-up apparatus. The minimum speed at which water can be raised varies with the height of the top of the tender delivery pipe above the trough but is generally about 20 m.p.h. ; the most effective speed is from 30 to 40 m.p.h. ; at higher speeds than that the frictional resistance of the water to very rapid motion results in a good deal of water being scattered in spray at the point of the scoop. This is clearly seen in the view of an express engine taking water at speed which appears in Plate 68.

Track-troughs have a certain vogue in America, but their most extensive use is in our own country, and it is by their aid that Great Britain is able to include in her time-tables the longest non-stop railway runs in the world. The longest unbroken railway run in the world is made twice daily in summer by the London and North Eastern Railway, when the 392¾ miles between King's Cross and Edinburgh are covered without intermediate stop, water being taken from seven sets of track-troughs *en route*. Absence of track-trough equipment increases the size of engine tender that must be carried, a striking example in our own country being the large eight-wheeled tenders attached to all the London and South Western express locomotive classes of the Southern Railway (Plate 75), despite the comparative shortness of many of the journeys over that system. In other countries the eight-wheeled tender is practically a standard equipment, while some of

the latest American and Canadian locomotives carry twelve-wheeled tenders. The tenders of the most recent Canadian National 4–8–4 express locomotives (Plate 19), indeed, find accommodation for no less than 13,500 gallons of water and 20 tons of coal. But economy is best served when the size and weight of the tender can be cut down to the minimum figure reasonably possible.

CHAPTER VII

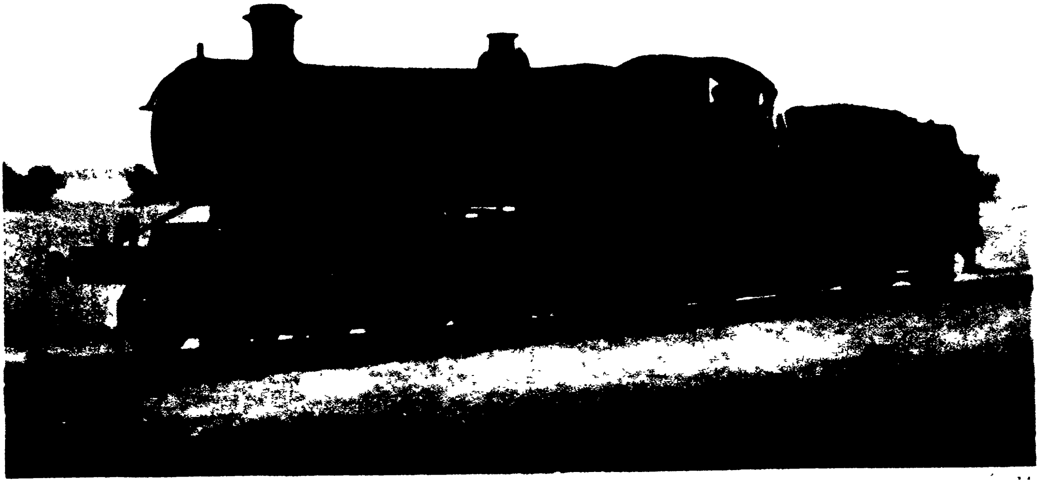
The Steam Locomotive—Cylinders and Motion

In the erection of a locomotive, which should be followed in the excellent series of illustrations of the course of building a " King George V " express locomotive of the G.W.R. in Plates 70 to 72 inclusive, and also in the cross-section of one of the L.N.E.R. " Pacific " express engines in Plate 61, the first portions to be placed in position in the erecting shop are the main frames. In British locomotives these consist of two deep steel plates, of 1 in. or 1⅛ in. in thickness, set up on edge and generally parallel to each other. The frames run from the front buffer-beam of the engine, from which the upper edge of both frame-plates can usually be seen, leading like knife-edges upwards towards the saddle which supports the boiler, and from there back to the cab. Strongly braced throughout their length, to maintain them at exactly their right distance apart, these frames, with their cross-bracings, form a rigid carriage which is, in effect, the foundation of the locomotive. To the frames are bolted the cylinders and the motion details; on them rests the boiler; and suitable recesses are slotted in them to house the axles, each contained in its axle-box. The framing must be of sufficient strength to withstand the stresses which are set up by the pressure of the steam alternately on the front and back ends of the cylinders; and also to transmit the pull of the engine, through the " draw-bar," to the tender and the train. In America the plate

frame is replaced by a "bar" frame, seen in Plate 69; this consists of a lattice-work of steel bars of about 4 in. or 5 in. square section, generally now made as steel castings in a number of large sections, which are welded or strongly bolted together. The advantage of the American method is a lightening of weight, but the bar frame is more subject to fracture when in service than the plate frame.

It can well be understood that the problem of dealing efficiently with the friction that arises in the axle-boxes of a locomotive, where the weight of the engine is transferred to the wheels, and in some cases a load up to 11 tons is bearing directly on an axle, is no small matter. It is met by arranging in the axle-box a portion of gunmetal, known as the "brass," which is bored out to the exact radius of the axle, and is then lined with some soft white metal alloy, which reduces the friction, and also protects the axle from damage in the event of overheating. The wheels themselves are entirely of steel. The "centres," including the spokes and the rim, are steel castings; the tyres, of specially hard steel—to withstand the same constant tendency to abrade away that we have already seen in the steel rail—are rolled in one piece, in order that they may have no welded joint in them. A perfect fit of tyre to rim is secured by heating the former, and then shrinking it on to the rim; before this is done the steel axle, which has been carefully turned to exact size, has been forced by hydraulic pressure into the hole left for its reception in the wheel centre.

Between the axle-boxes and the frame of the engine are interposed the springs, which are either of the "laminated" type, formed of a number of "leaves" of thin steel plate of a special "spring steel" quality, or—and more especially in the case of driving wheels—of the coiled or "helical" type. Springs are necessary, not only to preserve the



Pl. 64

2-8-0 ("Consolidation") Heavy Freight Locomotive, Great Western Rly. (pp. 111, 2[illegible])

L. 65 | L 125

"Pacific" (4-6-2) Express Locomotive, South Australian Rly. (p. 52).

locomotive as a whole from shocks, but also to assist in the exact distribution of its weight over the wheels. Considerable variation can be made by adjusting the tension of the various springs, and in this way the "adhesion weight" of the engine, to which reference was made in the last chapter, is definitely fixed. Every locomotive works is provided with a special weighbridge, capable of recording separately the weight coming down on each axle of the engine, by the use of which the various axle-loads are carefully adjusted.

We now pass to the driving mechanism of the engine. One particular difficulty of the British locomotive designer, arising out of our restricted construction gauge, concerns the disposition of his cylinders. In this country we are more tied down than in any other in regard to the maximum diameter of cylinder that can be used outside the engine, bolted to the outer side of the main frames. The 22-inch diameter cylinders fitted to the 4–6–4 Brighton express tanks of the Southern Railway represent about the utmost limit, whereas in America outside cylinders have been used of as large diameter as 30-in. and even 32-in. Similarly the diameter of inside cylinders is limited by the space available between the frames, which in its turn is restricted by the desirability of keeping the frames inside the wheels. No larger inside cylinders have been fitted in this country than the 21½-in. diameter cylinders of the 2-cylinder "Sir Sam Fay" type 4–6–0 engines of the Great Central section of the L.N.E.R. From these limitations has arisen the practice of using three or four cylinders in place of the previous two, in cases when exceptional tractive power is required.

There are other considerations bearing on this question. The use of inside cylinders tends to reduce the oscillation of an engine when running, as compared with outside

cylinders, where the disturbing forces are located further away from the centre-line. On the other hand, inside cylinders make it necessary to bend the driving axle of the locomotive into a double hairpin shape, to form the two cranks; the bigger the inside cylinders, so much greater the strain on the axle. In the case of wo-cylinder engines, British practice, which for many years favoured inside cylinders in place of outside, is now tending again towards the outside position; the Great Western Railway, for example, uses inside cylinders in none of its designs other than four-cylinder engines, and also certain 2-cylinder 0–6–2 tank engines built for services in the Welsh valleys, where limited clearances do not permit of the free use of outside cylinders. But in all the larger types, especially those intended for express passenger service, three or four cylinders are employed to yield the necessary tractive effort. In the case of a three-cylinder engine, two cylinders are arranged outside the frames, and one between them; whereas four-cylinder engines have two cylinders inside and two outside.

It is the London and North Eastern Railway which in this country has specialized chiefly in three-cylinder designs. The "Pacific" engines of the "Flying Scotsman" type are so equipped, as well as many other L.N.E.R. locomotive classes, but beyond one or two experimental engines, the only other 3-cylinder type of note (apart from 3-cylinder compound engines, to which reference will be made presently) is the new "Royal Scot" 4–6–0 class of the L.M.S. Railway. In all these engines, the three cranks are arranged to divide up the circle into three parts of 120 degrees each, with the result that the six "exhausts" from the three cylinders, to each revolution of the driving wheels, are all thrown out from the chimney separately; thus the three-cylinder engine can be distinguished readily

by its characteristically rapid puffing. The three-cylinder arrangement tends, with its six impulses to every driving-wheel revolution, to give to the driving axle a very smooth turning moment, or "torque": it has also the advantage of only requiring one cranking of the driving axle for the inside connecting-rod, instead of two in the case of a four-cylinder engine.

The four-cylinder arrangement has, however, been favoured by many railways, and in particular by the Great Western, all of whose 4-6-0 engines of the "Star" type (with its many sub-divisions), the "Castle" class and the new "King George V" type, are so arranged. It has the advantage over the three-cylinder type of needing only two sets of valve-motion to work all the four piston-valves, as compared with three sets in three-cylinder engines, or the ingenious "derived" motion (Plate 76) for the inside piston-valve adopted in the L.N.E.R. designs. The cranks of four-cylinder engines are usually arranged to divide up the circle into four equal parts of 90 degrees each, so that the exhausts are thrown out in pairs, and there is nothing to distinguish the puffing of these engines from that of ordinary two-cylinder engines. But in the "Lord Nelson" type of the Southern Railway two of the four cranks have for the first time—apart from a couple of earlier experiments—been advanced through 45 degrees, with the result that the driving wheels receive eight turning impulses to every revolution, and the engine puffs eight times to a revolution in consequence. The various arrangements of cranks just referred to are illustrated in Fig. 14.

The most even torque of all is given by the Southern four-cylinder arrangement, with its eight impulses per revolution, but the balancing of the engine is not so simple as that of a four-cylinder engine of the ordinary type.

Balancing is a very important factor in successful locomotive design. The swinging round of the heavy cranks, and other motion parts of the engine, sets up powerful disturbing forces which, if unchecked, would cause the engine to oscillate seriously, and even dangerously. These parts are therefore counterbalanced by crescent-shaped masses of steel incorporated in the rims of the coupled wheels.

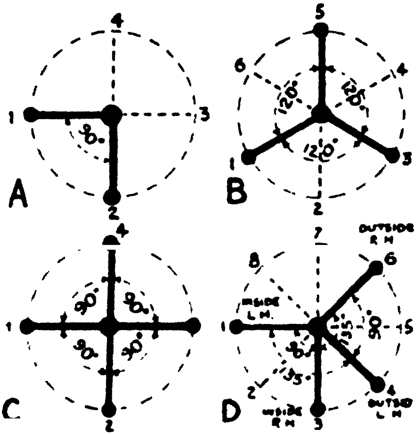


FIG. 14.—Arrangement of Cranks.—2, 3, and 4-Cylinder Engines.

(A) 2-cylinder engine. 4 exhaust beats per revolution of driving wheels.
(B) 3-cylinder engine. 6 exhaust beats per revolution of driving wheels.
(C) 4-cylinder engine. 4 exhaust beats (8 exhausts thrown out in pairs) per revolution of driving wheels.
(D) 4-cylinder engine, "Lord Nelson" type, Southern Railway. 8 exhaust beats per revolution of driving wheels.

At the chief locomotive works special "wheel-balancing" machines (Plate 74) are provided, on which the driving wheels, with their cranks and eccentrics, are spun round at high speeds, so that these balance-weights, which are hollow and are then filled with lead to the exact weight required, may be adjusted to a nicety. More difficult

to balance is the disturbing effect of the reciprocating motion of the engine. Pistons and piston-rods, in a two-cylinder engine in particular, tend to produce a swaying from side to side in a way that is often clearly visible when the engine is starting. Fully to balance these masses would set up other objectionable stresses, too complex to discuss here; the practice is, therefore, to balance the whole of the rotating masses of the motion, and roughly two-thirds of the reciprocating masses. It is the improved balancing obtained with three- and four-cylinder arrangements that has encouraged the recent increase in the maximum engine weights per axle that has been embodied in our latest British express locomotive designs, as mentioned in the last chapter. The "hammer-blow" on track and under-bridges, caused by badly-balanced locomotives, is, indeed, far more objectionable than mere dead-weight.

The linear, or "to-and-fro" motion of the piston in the cylinder is changed into the circular motion of the wheels by means of the connecting rods and cranks. Attached to the piston is the piston-rod, which passes through a carefully-packed "gland" in the back cylinder-end, and terminates at the "cross-head." To the cross-head is attached the "little-end" of the connecting-rod, which tapers outwards in size towards the "big-end"; this is the point of attachment to the crank. The diameter of the circle through which the centre of the big-end swings is, of course, equal to the maximum travel of the piston in the cylinder, and is known as the "stroke" of the cylinder; in modern British locomotives this dimension usually varies from 24 in. to 28 in., being only exceeded by the exceptional 30-inch stroke of the various Great Western outside-cylinder types. In outside-cylinder engines the connecting-rods turn the driving wheels by means of crank-pins, which form a part of the

wheel-centres Most of these parts are clearly illustrated in Plate 73.

It is essential that connecting-rods should not be too short, or they will take up a very angular position when the big-ends are at their highest and lowest positions, and tend to make the engine roll. Neither must they be too long, or they will have to be so heavy in design as to be unwieldy. In certain three-cylinder and four-cylinder types, in order that the cylinders may be in line with each other, all three or four cylinders are made to drive the leading coupled axle ; this is the case, for example, with the North Western " Claughtons " of the L.M.S., or the North Eastern " Atlantics " of the L.N.E R. But in other types, such as the Great Western four-cylinder 4–6–0 engines, in order to avoid the short connecting-rods necessitated by this arrangement, and also to reduce the strain on one driving axle, the drive is " divided," the inside cylinders being pushed out ahead of the smoke-box, and driving the leading pair of coupled wheels, while the outside cylinders are located further back, and drive the middle pair.

Steel of the finest quality must be used for the fabrication of the connecting-rods, coupling-rods, piston-rods, slide-bars, and other motion parts, as the constant stresses to which they are subjected when the engine is in motion are very heavy. A modern tendency is to use " alloy " steels for all these parts ; these steels contain minute proportions of certain elements such as nickel, chromium, cobalt and others, which add greatly to the hardness, and also, by means of subsequent heat treatments, to the toughness of the steel and its resistance to shock. In this way it is possible to cut down the dimensions of the motion parts without risk, which has the double advantage of reducing dead weight, and also of reducing the revolving weight which has to be balanced. One has only to compare

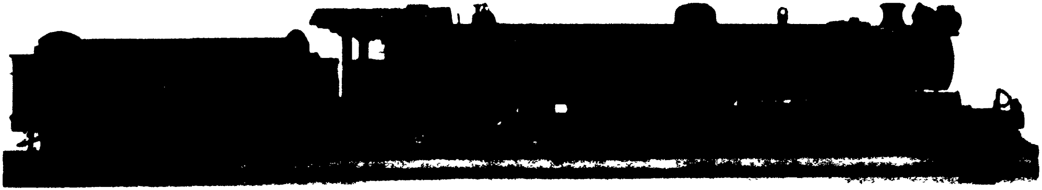
the light and graceful motions of the latest modern express engines, visible outside, with the heavy and clumsy gear of the engines of earlier days, to see how much has been accomplished in this way, notwithstanding the great increase in the power of the modern locomotive.

The cylinders themselves are cast from the best quality grey iron, and the preparation of the moulds for the castings, which generally include the steam-chests as well, and comprise two or even three cylinders with their steam-chests and steam passages in one casting, is one of the most difficult jobs undertaken in the ordinary course of iron-founding. When the castings are complete, the next operation is that of boring them to exact size; the sides of the bore must, of course, be perfectly parallel, or steam will leak round the rim of the piston from one end of the cylinder into the other. Another job requiring the utmost care and exactitude is that of fixing the cylinders in position inside or outside the engine; unless their centre-lines are exactly parallel with the centre-line of the engine, and in dead line with the centre of the driving axle, there is likely to be endless trouble afterwards owing to "heating" of the motion parts, and generally bad running of the engine Final adjustments to secure exact parallelism are made, if necessary, by bending the main frames of the engine. Before being mounted in position the cylinders and valve-chests are usually tested hydraulically to a pressure of 200 lb. per sq. in. or more. The upper part of inside cylinder and steam-chest castings is frequently designed in such a way as to act as a saddle for the front end of the boiler.

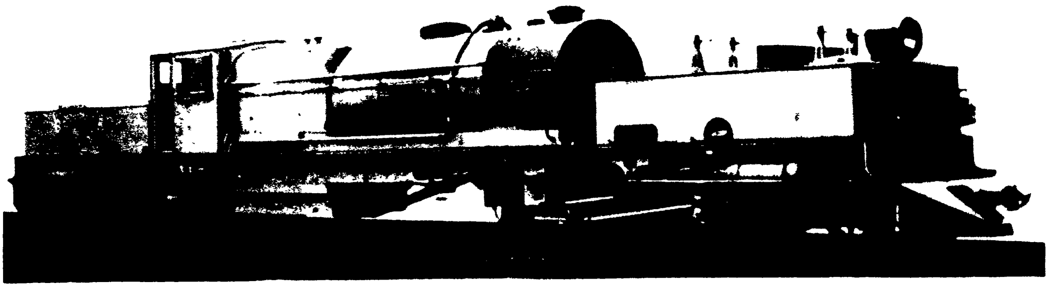
We now come to the function of the valves, and the method of their working. Robert Stephenson is credited with having been the first, in 1842, to foresee the importance of making the maximum possible use of the expansive

properties of the steam in the cylinder, although the invention concerned was not his own. It is the "expansion-gear," or "valve-motion," which performs the essential duty of moving the valves in such a way as to allow of this expansive working. At both ends of the cylinder are the "ports," or narrow openings which serve, both to admit the steam at the beginning of the stroke of the piston, and to release it again as the piston comes back on its return stroke. It is from the steam-chest that the steam passes into the cylinders, and the business of the valve is to regulate its passage. For a certain proportion of the forward stroke of the piston the steam must be allowed to enter the cylinder, pushing the piston forward; the valve must then close the port, allowing the steam to complete its work in the cylinder by expansion alone; then, as the piston begins its return stroke, pushing before it the partially-expanded steam back through the port by which it entered, the valve must immediately open an exit passageway for the steam to the chimney; and before the piston reaches the end of the return stroke, the valve must close, so leaving a little of the steam in the cylinder to act as a "cushion" for the piston as it comes to rest before moving forward once again. To execute these complex movements, the valve, which has a much shorter travel than the piston, must move rapidly just when the piston is moving the most slowly, at the two ends of its stroke.

In earlier locomotives, the valves were invariably of the flat type, shaped like a "⊓"; the inside of the "⊓" gave admission to the exhaust, while the live steam pressed on the outside. The chief objections to this type of valve—notwithstanding which it was in almost universal use on locomotives till well into the present century, and is still extensively used on older engines—



2-6-0 + 0-6-2 Mallet compound freight locomotive, South African Rlys.



Pl. 67. A 152.

2-8-0 + 0-8-2 Garratt locomotive, Burma Railways.

Articulated Locomotives (p. 117)

K 133.

The "Royal Scot" Express, L.M.S., taking water from Bushey Troughs (pp. 119, 121, 215, 237)

are that the steam presses the flat valve against the face to such an extent that energy is dissipated in friction; and also that the path of the exhaust steam out under the valve is so constricted, as well as roundabout, that further loss of energy occurs by the back pressure of the used steam, which cannot escape freely, against the returning piston. So the present piston-valve was devised to overcome the objections, and is used in most modern locomotives. In the case of outside cylinders, the circular steam-chest can be readily seen above the cylinder proper. The piston-valve chest (Plate 61) is, in design, similar to an ordinary cylinder, except for having two pistons, one at each end. Steam is led direct into the space between the two pistons, while the smaller spaces at the outer ends of the valve-chest communicate with the exhaust pipe. Occasionally, but infrequently, this arrangement is exactly reversed, in which event the piston-valve becomes of the "outside admission" instead of the "inside admission" type. The advantage of the piston-valve is the virtual elimination of the frictional resistance which is so troublesome with the flat slide-valve, and, with inside admission, the fact that there is only back-pressure on the valve-spindle glands.

The movement of these valves is effected by means of the valve-motion, as previously mentioned. Of this there are many varieties, but in the locomotive practice of this country, two of these varieties predominate. There is the older "Stephenson link-motion," and the newer and now widely-used "Walschaerts" valve-motion. The former (Fig. 15) derives its motion from two eccentrics, fixed on the driving axle of the engine, the rods of which are fastened to the two ends of a curved "link," which can be lifted or lowered by means of the driver's reversing lever or screw. The interior of this link is slotted out, and in it slides a block

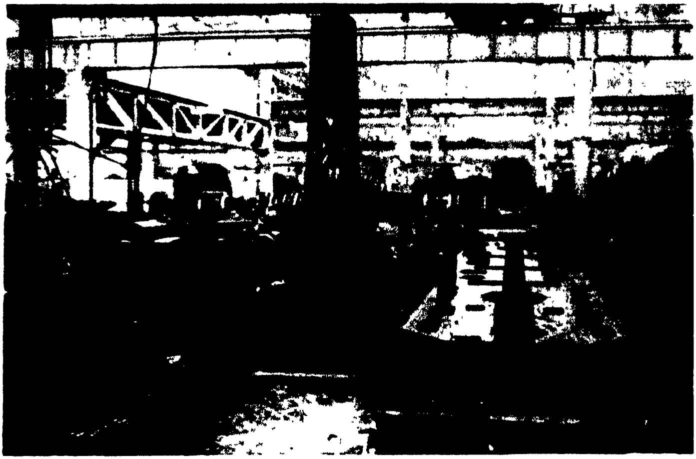
connected to the valve-spindle; the movement of the block, and with it of the valve-spindle, is governed by the position of the link. When the link is in mid-position, and the block in the centre of the slot, there is no movement of the valves at all; with the block at one end of the link the valves have their maximum of travel in "forward" gear, and when the block is at the other end, the valves are travelling their maximum in "reverse" gear, and the engine, of course, is running backwards. When the valves are at their maximum travel, the steam enters the cylinder for about three-quarters of the stroke of the piston. As the engine gets into speed, however, the driver, by "notching up" or moving his reversing lever—and with it the position of the link in relation to the block—reduces the "cut-off" from this 75 per cent. position to as little as 20 per cent., or even 15 per cent., in some modern engines, so making the utmost use of the expansive properties of the steam, which then does its work by expansion during the remaining 80 or 85 per cent. of the stroke.

In the Walschaerts gear (Fig. 16), the motion is derived partly from one eccentric only, and partly from the cross-head. In outside cylinder engines, where this motion is usually found, a crank pivoted to the crank-pin takes the place of the eccentric, and the whole of the motion is located outside, as, for example, in the locomotives shown in Plates 52, 75 and 101. This transfer of working parts to the outside of the locomotive is one of the respects in which the British locomotive of to-day has altered considerably in appearance, as compared with years gone by, but it must be remembered, at the same time, that the outside arrangement of working parts makes them much more readily accessible, for purposes of inspection and repair, and so tends to reduce the cost of maintaining the locomotive. Opinion is divided as to the relative merits of the Stephenson and the

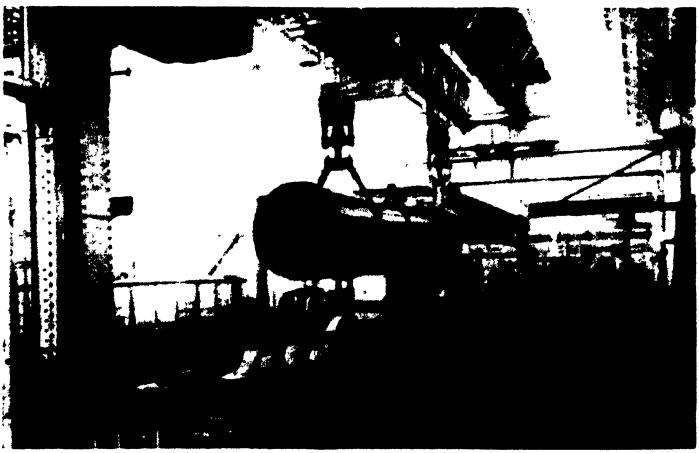
[illegible] bar-frames (p. 124)

[illegible] on its Wheels

Building a "Confederation" Class Locomotive Canadian National Railways (p. 124)



Frame plates [illegible]



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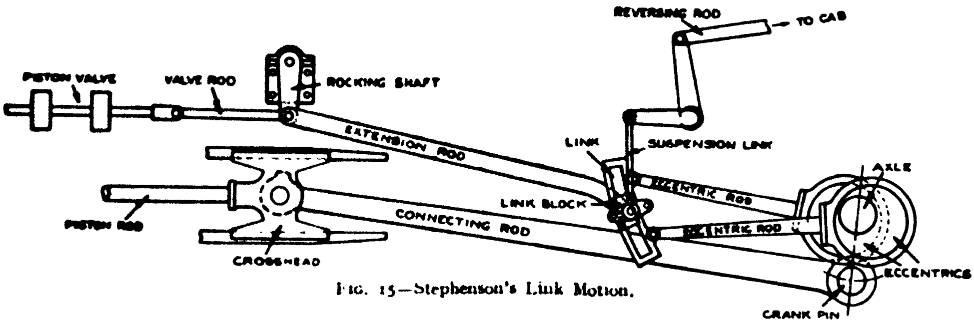


FIG. 15—Stephenson's Link Motion.

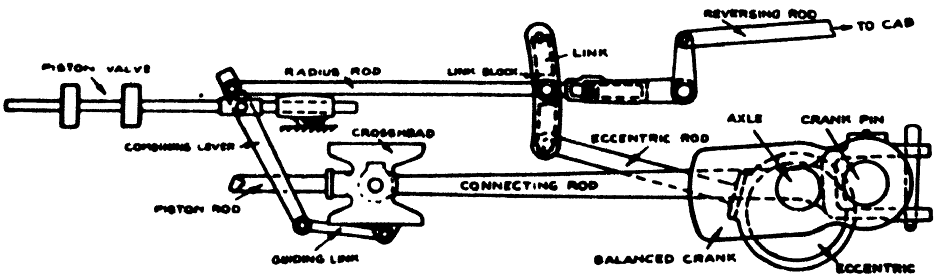


FIG. 16.—Walschaerts Valve Motion.
This is the arrangement adopted by the Great Western Railway, located between the frames, in which one eccentric is used; the more general arrangement is outside the frames, without an eccentric.

Walschaerts motions, but the simpler construction of the Walschaerts gear, dispensing entirely with eccentrics when it is arranged outside the frames, is the chief reason why it is more extensively used in all parts of the world than any other, in locomotive work.

Throughout the whole course of locomotive history experiments have been carried on unceasingly with a view to increasing the thermal efficiency of the steam locomotive. Locomotive design, as we have seen already, is ruled by the narrow limits of space within which the railway rolling stock must pass when in motion, and also by definite limitations of weight. Within these limits there must be designed a power-house on wheels, capable of exerting a very high tractive power in proportion to its own weight, but at the same time able to adapt its tractive capacity readily to meet a wide variation in power demand, according to the varying demands of road, load and schedule speed. Despite the low overall thermal efficiency of the steam locomotive of traditional design, no other type of locomotive —short of electrification—has yet been designed which, when all the costs of construction and maintenance, in addition to those of running, have been taken into account, is, in the long run, more adaptable to these peculiar conditions of working and more ultimately economical than the ordinary steam locomotive. Thus it is that, apart from constant improvements in detail, with the object of still further increasing both thermal and mechanical efficiency, the steam locomotive of the type to which we are most accustomed is likely still to enjoy a lengthy lease of life.

The chief loss in thermal efficiency arises out of the fact that the escaping steam from the cylinders, only partially expanded and still containing valuable energy, must be thrown to waste out of the chimney, in order to provide the necessary draught for the fire. It is when the percen-

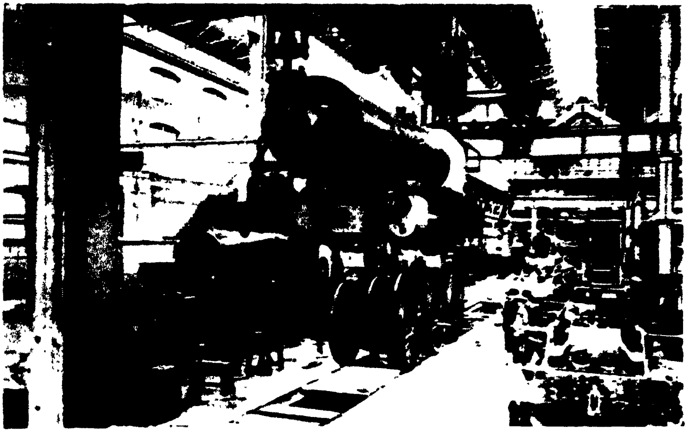
tage of cut-off is at the highest that this loss of energy is the greatest. Again, as any length of boiler barrel much exceeding 15 ft. inclines to be a disadvantage rather than an assistance to efficient steaming, the shortness of the boiler inevitably results in much unused heat from the fire passing out of the chimney as well. These are the two most important sources of lost energy, but by no means all. As the speed of the engine increases, and the cut-off is brought back to a lower percentage, the travel of the valves is reduced, and in the case of many locomotive types whose designers have only allowed for a comparatively short travel of the valves, this reduction of cut-off has various results that impair efficiency.

The cylinder ports are not opened sufficiently rapidly at the beginning of the piston stroke, so that the steam is "strangled" on its entry, and a drop in pressure results. Later on in the stroke the exhaust port closes too soon, trapping a substantial volume of steam in the end of the cylinder which, unable to escape, is compressed by the piston, perhaps to an even greater pressure than that of the "live" steam in the steam chest; this tends to make the big-end of the connecting rod "knock" badly as it rotates, with the danger of overheating. There must always be some compression in the cylinders, to form a "cushion" for the piston at the end of the stroke; but it is excessive compression which is objectionable, as, apart from the damaging effects to the motion, it is in the nature of "negative" work, and so results in a further loss of efficiency. Again, the rapid expansion of the steam in the cylinders, with the proportionate drop in temperature that it entails, tends to cause condensation of the steam on the cylinder walls, this being a further source of lost energy.

It must be remembered, however, that were the action of the cylinders and valve-gear of the locomotive perfect, it

would be only possible, in any event, to utilize for the propulsion of the train a small proportion of the energy which has been put into the generation of the steam. Most of the energy developed in the combustion of the fuel goes to boil the water in the boiler, and but a small proportion to the subsequent accumulation of the steam at high pressure. If the valve-gear were to permit complete expansion of the steam, from its original pressure down to atmospheric pressure, the steam must perforce be still exhausted as steam, and all that large proportion of the heat expended in its generation, known as "latent" heat, must be lost. Thus a perfect locomotive engine of traditional design could not have a greater thermal efficiency than about 15 per cent.; while the imperfections of the valve-gear, together with the loss of heat from the boiler, together reduce the actual thermal efficiency figure to about 7 per cent., even in the best test conditions, and to a lower figure still in normal working.

In the past the cheapness in Great Britain of fuel of the best quality has to a certain extent, perhaps, impeded the development of the British steam locomotive in the direction of increased thermal efficiency, but present indications are that every locomotive engineer in the country is alive to the urgency of the problem. As regards locomotives of ordinary design, it is probably fair to claim that, of all British railways, the Great Western has made the greatest strides towards efficient locomotive working. Under the direction, first, of Mr. G. J. Churchward, and later of Mr. C. B. Collett, the Swindon locomotive works has specialized in a combination of high working pressures, large-diameter piston-valves with an unusually long valve-travel, and exceptionally large steam and exhaust ports. Of all these factors, the length of valve-travel is one of the most important. The friction occasioned by



Pl. 71 A 138

Asbestos [illegible]

Construction of "King" Class Express Locomotives at Swindon Works, G.W.R. [illegible]

[illegible]

Pl. 72. [illegible] P. 130

[illegible]

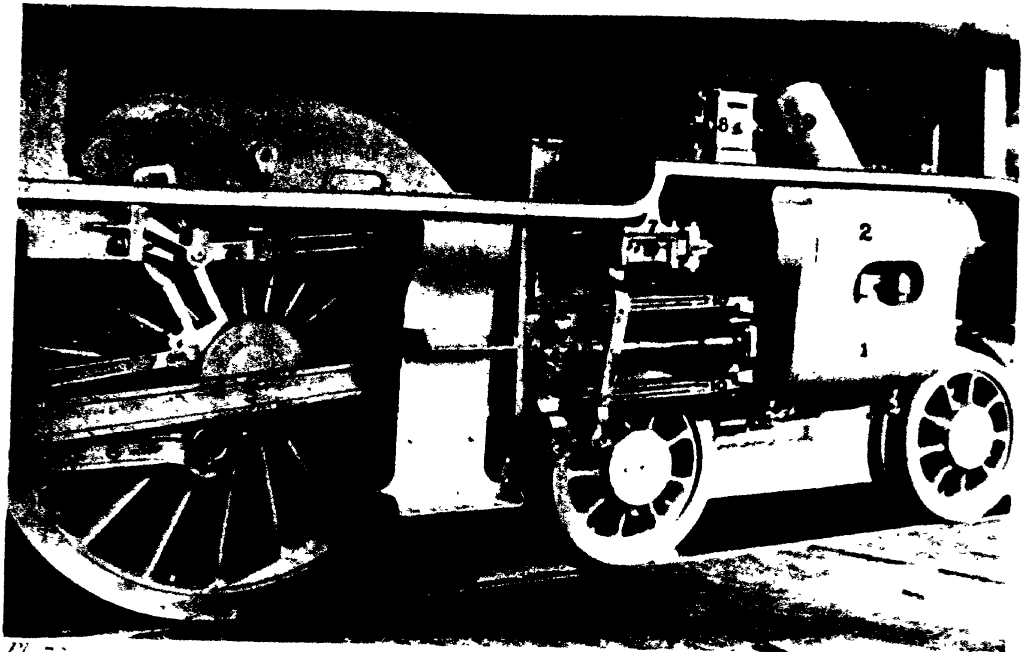
[C]onstruction of "King" Class Express Locomotives at Swindon Works

steam pressure on the back of the old slide-valves probably accounts in large measure for the prejudice of British locomotive engineers against increasing the length of travel, but the use of piston-valves has done away with the objection. As far back as 1902 the Great Western Railway introduced the first 4–6–0 express passenger locomotive—No. 100, "William Dean," now No. 2900—to embody all the features above-mentioned and they have been found in every subsequent Great Western design. But nearly a quarter-of-a-century elapsed before the lead so given was followed seriously by other British railways.

The effect of a long valve-travel is that it is possible to work an engine in very short cut-offs without the excessive compression in the cylinders to which reference has just been made. This, in its turn, permits a driver to keep the regulator of the engine fully open for long periods; as a result there is no "throttling," or constriction of the steam as it passes into the steam-pipe, which involves a substantial reduction of the pressure of the steam before it is used in the cylinders. These two features in combination are therefore productive of a double gain in efficiency, by the absence of throttling and the better use made in the cylinders, by the longer cut-off, of the expansive properties of the steam. Raising the pressure in the boiler, again, while it entails a stronger boiler and somewhat higher constructional expense, supplies to the cylinders steam with a proportionately greater capacity for expansion. Another important feature of Great Western designs is the size of the ports, and the resultant freedom with which the exhaust steam can get away up the chimney after use must be apparent to any reader who has listened to the explosive suddenness with which a Great Western engine throws out its steam on starting, and, on the other hand, to the silence of its running at high speeds. This unhindered

exhaust from the cylinders of Great Western express engines is largely responsible for the feats of sustained speed for which they are noted. As indicated in the last paragraph, the same important features of design are embodied in the latest locomotive types of other British groups, such as the super-"Pacific" "Enterprise" type on the L.N.E.R., the "Royal Scot" 4-6-0 type of the L.M.S., and the "Lord Nelson" and "King Arthur" 4-6-0's of the Southern.

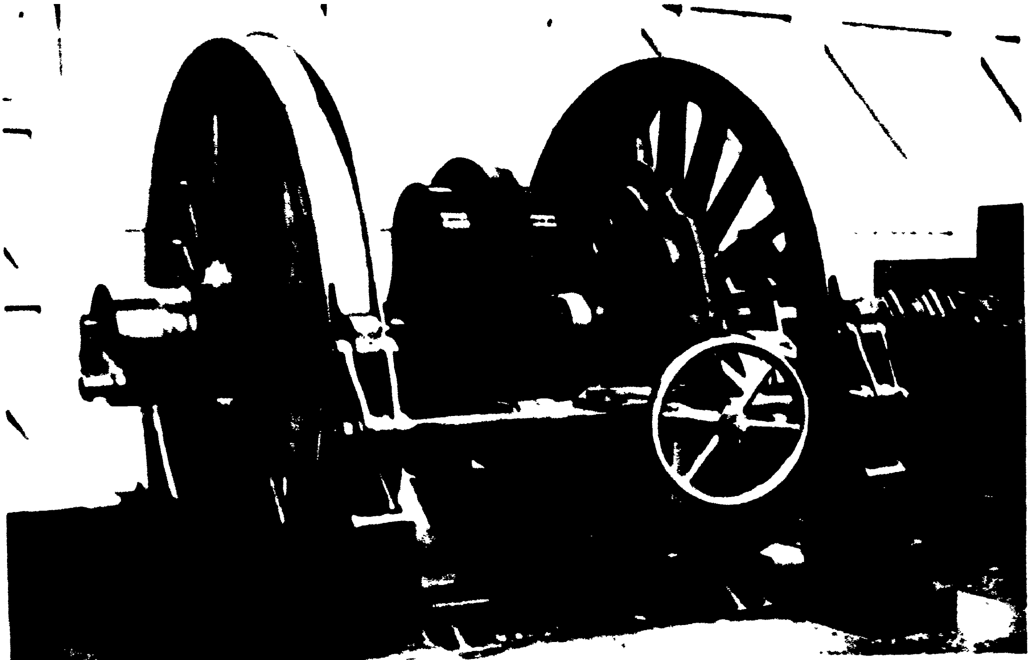
Increase of boiler pressure to far higher extremes than ever previously attempted in locomotive practice is a feature of one or two remarkable locomotive developments of recent date. The Delaware, Lackawanna and Western Railway of the United States has produced a couple of engines for freight service, one with a boiler pressed to 350 lbs. per sq. in., and the other—the "John B. Jervis," illustrated in Plate 77—carrying 400 lb. per sq. in. In Germany and Switzerland successful experiments have been made with locomotives working at no less than 882 and 850 lbs. per sq. in. of steam respectively, but both boilers and engines have been so modified in each case as to present very considerable variations from traditional steam locomotive design. In the German engine—a 4-6-0 express passenger locomotive adapted for the purpose—the high-pressure steam, which is generated in an enclosed drum above a water-tube firebox, is expanded in a high-pressure cylinder between the frames, whence it is led to two outside low-pressure cylinders, reinforced on the way with a supply of steam at 206 lb. per sq. in. pressure, generated in a boiler-barrel of the normal type. The Swiss high-pressure engine, which is of a 3-cylinder simple type working at 850 lb. per sq. in., has shown an economy of 35-40 per cent. in coal consumption, and 47-55 per cent. in water, over an ordinary locomotive of



Pl. 73.

Cylinders and motion of L.M.S. 4-6-4 Tank Locomotive

1. Cylinder 2. Piston valve chest [illegible]



F. 74 K 141.

Wheel-balancing machine Doncaster Works L.N.E.R. (p. 128).

equal weight. Similar experimental engines are now being built for the British L.N.E. and L.M.S. Railways.

Many other experiments have been tried, with the object of increasing thermal efficiency, and some are rapidly becoming established as of considerable value. Among these may be mentioned the use of "poppet" valves of the Caprotti and Lentz types, both of which have been tried extensively in Great Britain. In these the admission of steam to the cylinders and its exit are controlled by lifting valves instead of sliding valves, the lifting being effected by cams working off a cam-shaft, which in its turn is operated by the motion of the engine. It is claimed for these valve-motions that they enable the ports to be opened and closed at exactly the moments required, in order to obviate the troubles mentioned earlier in this chapter; and certainly the experimental engines of both types (0-6-0 goods and 4-6-0 express engines with "Lentz" gear on the G.E. section of the L.N.E.R., with 3-cylinder express 4-4-0's of the "Shire" class (Plate 79), and 4-cylinder 4-6-0's of the "Claughton" type with "Caprotti" valves on the Western Division of the L.M.S.) have shown themselves capable of working on much lower percentages of cut-off than any of the ordinary engines of the same types. The increase of efficiency, as expressed in reduced coal consumption, is so marked that further engines are being so fitted on both railways.

Another series of experiments, of a different kind altogether, has been made with locomotives in which cylinders and reciprocating motion have been abandoned in favour of steam turbines. After use in the turbines the steam is led into a condensing plant, where its heat is absorbed; draught for the fire is provided by a fan arrangement. Of all the turbo-condensing engines tried, the Ljungström, of which an example has worked experimentally over the

Midland Division of the L.M.S. and has proved itself more than competent to handle the ordinary expresses to time between London and Manchester, has been the most successful, but as yet has not shown the economy in coal consumption which alone could justify the additional cost of building and maintaining a locomotive of this type. In its native country of Sweden the first successful Ljungström turbo-condensing locomotive has shown an overall thermal efficiency of 14·7 per cent. on test, but there is no evidence, as yet, of any ultimate economy, taking capital cost into account.

We come, lastly, to the compound locomotive. In this the expansion of the steam is divided into two successive stages, being begun in one or two cylinders taking high-pressure steam direct from the boiler, and continued in one or two cylinders of larger volume ere it is thrown out of the chimney as exhaust. Compounding, of course, is no new solution of the efficiency problem. In marine engine practice and large stationary engines it has been employed for many years past; its first application to the locomotive was by a French engineer named Mallet, in 1876. Since then it has come into very wide use in certain Continental countries—particularly France and Germany (Plate 78), where, with locomotive coal of inferior quality, close attention has been paid for many years to the question of locomotive efficiency. In England, however, with the exception of one notable design, the compound locomotive has never found favour. Compound engines were largely built on the late London and North Western Railway, under the régime at Crewe of the late Mr. F. W. Webb, up to the beginning of the present century, and to a lesser extent on the late North Eastern and Great Eastern systems also, but the defects of the systems tried were such that the engines were never

really successful, and with one or two exceptions have all been scrapped or converted to simple propulsion. The successful compound design just mentioned is that initiated on the late Midland Railway by Mr. S. W. Johnson in 1902, and since improved by his successors at Derby, Mr. R. M. Deeley and Sir Henry Fowler. Since the formation of the L.M.S. group, these engines (Plate 79) have been extensively built as one of the standard L.M.S. express passenger types, until there are now over 200 of them at work on all parts of that great system.

The chief advantage of the compound locomotive is that the range of expansion in each cylinder is reduced, and with it the fall of temperature of the steam and the resultant condensation. It also enables a high overall degree of expansion of the steam to be obtained without the compression difficulties which occur when the cut-off is greatly reduced in a single-expansion cylinder. But to attain its maximum success, the compound locomotive must employ high pressure steam, which, at the same time, it is able to put to more economical use than the simple locomotive. Arrangements must also be made to supply high pressure steam to the low pressure cylinders when the engine is starting, or a very slow start will be the result; this was one of the defects of the Webb compound engines on the L. & N.W.R., which had to start away in full compound working, and were very sluggish in consequence. In the L.M.S. Midland compounds, which have one high pressure cylinder between the frames and two low pressure cylinders outside, the driver opens the regulator only a little way when the engine is starting, and uncovers a small port which conducts steam from the boiler straight to the low pressure cylinders; later, as the train gets into speed, the regulator is pushed fully over, and the steam is conducted to the high pressure cylinder instead. Full compound working then

begins, the steam, after its partial expansion in the high pressure cylinder, being conducted to a "receiver," or intermediate steam-chest, and from there to the low pressure cylinders for its final stage of expansion. The more common starting arrangement, however, is to fit the compound engine with an automatic valve which admits live steam to the low-pressure cylinders whenever the steam in the low pressure steam-chest falls below a certain predetermined figure.

It is important in compounding that the volume of the low pressure cylinders shall be suitable to receive the partially-expanded steam from the high pressure cylinders. It was one of the causes of failure of many of the Webb compounds that the former were too small; the Midland compounds, however, with one high pressure cylinder of 19 in. diameter and 26 in. stroke, and two low pressure cylinders of 21 in. by 26 in., have what appears to be an ideal volume ratio of about 1 to 2½. The cut-off in the high pressure cylinder or cylinders is usually effected later than in the low pressure cylinders; in the Midland engines this is arranged to operate automatically, but in many of the Continental designs the high and low pressure cut-offs are independently under the driver's control, and the amount of brain-work needed to get the best out of the engines is thereby increased. The great majority of the Continental compound locomotives are of four-cylinder types, and the work performed by some of them—especially the wonderful "Super-Pacifics" (Plate 80) of the French Northern Railway—is amply sufficient to prove the value of compounding. Lengthy and detailed experiments which have been made, too, by M. Marechal, the Chief Mechanical Engineer of the P.L.M. Railway of France, have placed beyond doubt the economy of the compound principle. In the course of time we shall almost certainly

hear more of compounding in Great Britain ; and already the Americans are turning their attention again to the compound locomotive as a solution of the efficiency problem.

Other aids to increased efficiency—such as the superheating of steam—belong more properly to the next chapter, and need no description here. But before concluding this description of the locomotive *chassis*, it is well to mention the usual calculation whereby an estimate is reached of the tractive power of a locomotive. The formula employed in the case of simple engines is this :—

$$T = \frac{d^2 \times s \times p}{D}$$

where T = Tractive Effort, d = diameter of cylinders, s = stroke of cylinders, p = mean effective pressure, and D = diameter of driving wheels. The " mean effective pressure " of the steam as it reaches the pistons is usually regarded as 85 per cent. of the working steam pressure. The latter is taken in lb. per sq. in., and all the other dimensions in inches, the result, which expresses the maximum tractive power of the engine, being given in pounds. In the case of a 3-cylinder simple engine the result should be multiplied by 1·5. and in that of a 4-cylinder simple by 2. The calculation for a compound engine is rather more complicated, and is based on an estimation of the mean effective pressure in the various cylinders. This formula of course assumes that the boiler of the locomotive is able to supply steam in sufficient volume to make the tractive effort continuously effective, and therein lies the limited value of the calculation.

CHAPTER VIII

The Steam Locomotive—The Boiler and the Fuel

A FAMOUS locomotive engineer is credited with having said that the measure of a locomotive's success is its "capacity to boil water." This was Mr. H. A. Ivatt, Locomotive Superintendent of the late Great Northern Railway. When he assumed command at Doncaster Works, the tendency of locomotive engineers was to mate large cylinders to small boilers, and many successful designs of previous years were being spoiled because their designers imagined that they could be made to perform harder work by the simple expedient of enlarging the cylinders alone. In the year 1902, Mr. Ivatt created a revolutionary precedent by producing his first large-boilered "Atlantic"—No. 251—whose 5 ft. 6 in. diameter boiler was the largest that this country had then seen, whereas the cylinders, which were only 18¾ in. diameter by 24 in. stroke, were smaller than was customary with the far smaller-boilered 4-4-0 express engines of that period. In these engines (Plate 81) Mr. Ivatt produced a design of far-reaching influence in Great Britain. As we saw in the last chapter, until the Great War coal of the best quality was always cheap as well as abundant. So the small engines with the big cylinders could be "thrashed" when occasion demanded—that is, worked with a regulator wide open and a long cut-off, making a fierce draught and burning coal at a tremendous rate—provided that there was no great insistence on economy of coal consumption. To-day,

however, the tendency is towards the use of the large-boilered engine, which at times appears excessively large for the work it is called upon to do, but at the same time is always capable of burning the fuel thoroughly on its ample firegrate, and of obtaining the maximum value from the heat thus developed by a boiler heating surface of large area.

But this is anticipating the features of design of the locomotive boiler, which must be our next consideration. It was George Stephenson who first incorporated in a locomotive jointly the principles of a multi-tubular boiler, on the one hand, and the use of the escaping steam from the cylinders to afford the necessary draught for the fire, on the other. Neither of the ideas was his own, but their association in this way in Stephenson's famous "Rocket" set the final seal of success on the steam locomotive. Since then the design of the locomotive boiler has undergone unceasing improvement, but the basic principles remain unchanged. The boiler (Plate 82) is divided into three parts. At the front end, surmounted by the chimney, is the "smokebox"; at the rear end is the "firebox"; and joining the two together is the "barrel." The smokebox and the firebox are supported on the front and rear ends of the frames respectively, the barrel forming an unsupported length between them, except in the case of certain larger locomotives, in which an intermediate support is provided. There are two parts to the firebox—the inner firebox, which actually contains the fire—and the outer firebox. Both the smokebox and the inner firebox are securely shut off from the barrel by stout tube-plates, but communication is established between them by means of between two and three hundred tubes of about 1¾ to 2 in. diameter. The water in the boiler thus surrounds each one of these tubes, as well as the inner firebox.

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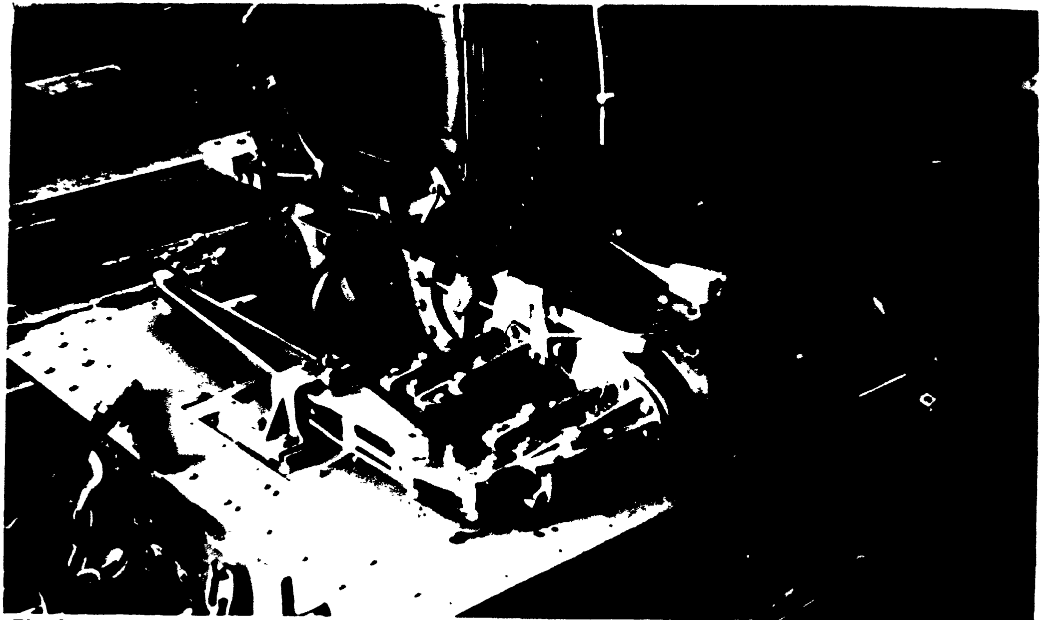
The general principle of steam-raising may be followed very clearly in the cross-section of one of the large "Pacific" express locomotives of the L.N.E.R. which constitutes Plate 61. The "exhaust" steam, after it has done its work in the cylinders, is led into the blast-pipe, which stands in the centre of the smokebox, immediately under the chimney. This pipe is designedly of narrower dimensions at the top than it is at the bottom, that the force with which the steam is ejected into the chimney may be increased. In order that the necessarily short chimney of to-day may have sufficient effective depth for this purpose, it is provided with a downward extension into the smokebox, known as a "petticoat." In its violent passage through the chimney, the exhaust steam creates a strong suction, which results in the formation of a partial vacuum in the smokebox; to ensure the creation of the vacuum, it is essential that the front door of the smokebox be closed and secured as tightly as possible. There is only one other direction from which air can be drawn to fill the vacuum, and that is through the boiler tubes, which form, as we have seen, an open passage from the inner firebox to the smokebox.

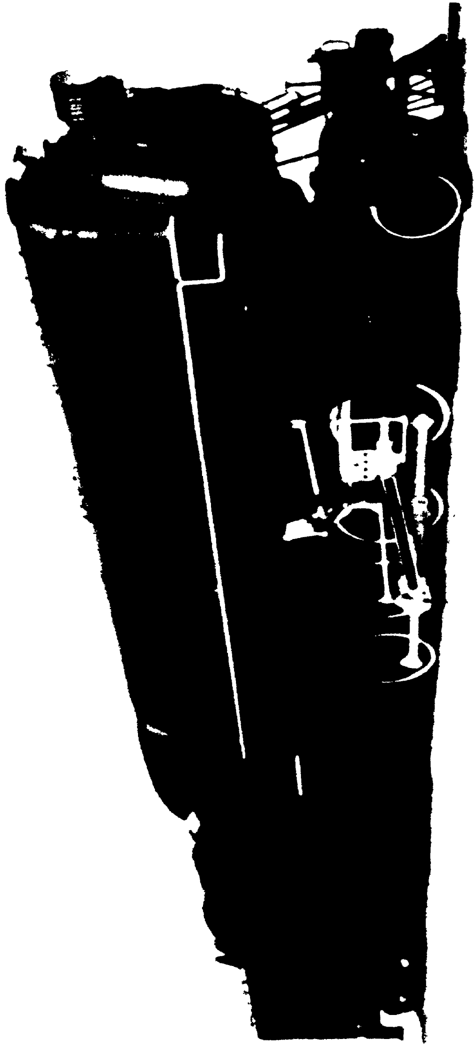
Air is drawn, therefore, from under the ashpan by means of dampers which are provided to regulate its admission, and through the firegrate and the fire, and, to a certain extent, through the firehole door also; thus an ample supply of oxygen is provided for the thorough combustion of the fuel, the products of that combustion being drawn through the boiler tubes, by reason of the smokebox suction, and ultimately thrown out of the chimney. But on their way these heated gases, surrounded by water as they pass through each one of the tubes, make their contribution to the steam-raising; this goes on constantly, not only in the space between the inner and outer fireboxes, which



Pl. 76. L 148.

The Gresley Derived Motion for 3-cylinder Simple Locomotives (p 127).

The rocking-shaft in foreground derives its motion from the extended piston valve spindles to left and right, and communicates the motion to the spindle of the centre piston valve seen on the right hand of the centre cylinder end.



is the hottest water space in the boiler, but round the margin of each boiler tube as well. The outer surface of the inner firebox, added to the aggregate outer surface of the whole of the tubes, gives what is known as the " heating surface " of the engine.

The reader can well understand, as he considers the method of raising steam in a locomotive boiler, what a nicety of balance must be preserved in the proportioning of the details, if the engine is to do its work properly, on the one hand, and is to be economical in its consumption of fuel, on the other. Too small an orifice to the blast-pipe, for example, will mean too fierce a blast, with the result that, by reason of a violent draught, much of the fuel will be drawn out of the chimney in a partially-consumed state and thrown to waste. A locomotive exhaust which can be heard miles away, and showers of sparks issuing from the chimney, are a poor advertisement for the efficiency of the engine concerned. Too large an orifice, again, may result in insufficient draught, with the result that the fireman may have a difficulty in keeping up the boiler pressure. The Great Western authorities solve this problem in an ingenious way by using a " jumper top " to the blast-pipe. This is a casting which rests on the top of the blast-pipe proper, and when the blast tends to become fierce, is lifted by the pressure of the steam, and uncovers a series of holes drilled round the blast-pipe, near the top, thus affording an additional outlet. As soon as the engine is working more easily, the " jumper top " falls again to its normal position.

Then, again, exceptional area of heating surface does not of necessity mean exceptional power of raising steam It is possible so to crowd the barrel with masses of small diameter tubes as to obstruct the free circulation of the bubbles of steam through the water. In all these matters it is the

experience of years which alone can dictate the most suitable proportions, not only for the parts of the boiler, but for the whole of the locomotive dimensions. Often when the first engine of a new type has been completed, many alterations are found necessary, after the first experimental runs have been made, in order to secure maximum efficiency. It is on record, for example, that the famous Southern express engine " Lord Nelson " had four successive enlargements carried out on the top of the blast-pipe before the ideal dimension was reached—a tribute to the design of the boiler, which permitted of steam-raising at an adequate rate with so comparatively soft a blast. Many of the later engines of the Midland compound type on the L.M.S., again, were built with cylinders ⅛-inch larger in diameter than those of the earlier engines ; but it was found that they did not work as efficiently as before with the larger dimensions, and their cylinders had therefore to be reduced in diameter to the previous size by the expedient of " lining up." There is no finality in locomotive design.

The details of boiler construction now need closer consideration. For the smokebox a construction of steel plates is employed. The front end of the smokebox is generally " extended " forwards, in order to catch as much as possible of the ash which is drawn through the boiler tubes by the blast, and so to prevent the former from being thrown out of the chimney. Siemens-Martin or " open-hearth " acid steel of the finest quality is used for the construction of the barrel, which has to withstand a very high aggregate pressure when steam has been raised. The barrel normally consists of two or three " rings," like the sections of an extended telescope ; each ring is a single steel plate rolled round to the correct radius and then securely joined by riveted cover-strips. These are riveted by means of hydraulically-operated machines (Plate 85)

which help to press the plates tightly together at the joints, and so to keep the boiler steam-tight. Occasionally short barrels are made from one plate only, which reduces the number of joints to a minimum. For the outer firebox steel is also used, but the preference in our own country for an inner firebox material lies with copper. This is partly because copper is a better conductor of heat than steel, and partly because copper withstands better than steel (whicht ends to crack) the constant expansion and contraction resulting from the variations of temperature in the firebox. For the boiler tubes a variety of materials can be employed, but steel is generally preferred as being the cheapest.

Careful provision must be made in boiler design to resist the enormous internal pressure, to which reference has been made previously. In the latest British express locomotive designs, for the purpose, as explained in the last chapter, of increasing efficiency, the working pressure has been advanced to the high figure of 250 lb. per sq. in., as compared with the pressure of about 180 lb. more generally used in Great Britain. The inner firebox has thus to be secured to the outer firebox by hundreds of copper or steel "stays," or stout bolts screwed at both ends, which keep the two surfaces at the right distance apart (Plate 87). These stays pass through the water-space both at the top, the back and the two sides of the inner firebox. Calculation will show that in a powerful modern locomotive the roof stays of an inner firebox may have to withstand a total pressure of 400 to 500 tons, and the side stays of between 800 and 1,000 tons. In the same way the extreme back of the firebox is stayed to the front tube-plate by a small number of longitudinal stays which pass through the length of the boiler barrel; the firebox tube-plate is, of course, tied to the front tube-plate by means of the tubes themselves. The practice of

fitting engines with the "Belpaire" firebox—standard in all Great Western designs (Plate 87) and all the latest L.M.S. engines—with its characteristic straight sides and flat top, has arisen largely from the fact that this shape simplifies the troublesome problem of staying, in addition to providing the greatest steam space at the most valuable point, immediately above the inner firebox. At the bottom of the firebox both outer and inner boxes are riveted firmly, the one on the outside and the other on the inside, to a heavy cast steel ring of about 3½ inches square section, known as the "foundation ring," clearly seen in Plate 85.

Another type of firebox, employed in the Great Northern "Atlantic" and "Pacific" designs of the L.N.E.R., is the "wide" firebox. It is only practicable to use this in a locomotive which has a pair of idle wheels behind the coupled wheels, as this type of box rests on the top of the frames, and spreads across the whole available width of the engine. It originated in the "Wootten" type firebox of America, designed to burn fuel of poor quality, and so large, in the case of some earlier American engines, that the driver had to be provided with a cab in front of the firebox, perched astride of the boiler, in order to get a proper look-out ahead. The wide firebox gives a much larger area of firegrate than the ordinary Belpaire or round-topped firebox; the L.N.E.R. "Pacifics" (Plate 52), for example, have 41¼ sq. ft. of firegrate, as compared with the 33 sq. ft. of a Great Western "King" or the 28 sq. ft. of one of the L.M.S. "Royal Scot" class. But opinion is divided as to whether the large square box of the former type, or the long narrow box of the latter, gives the best results from the steaming point of view.

One more detail of firebox equipment should be mentioned. For the proper combustion of fuel, it is essential that the

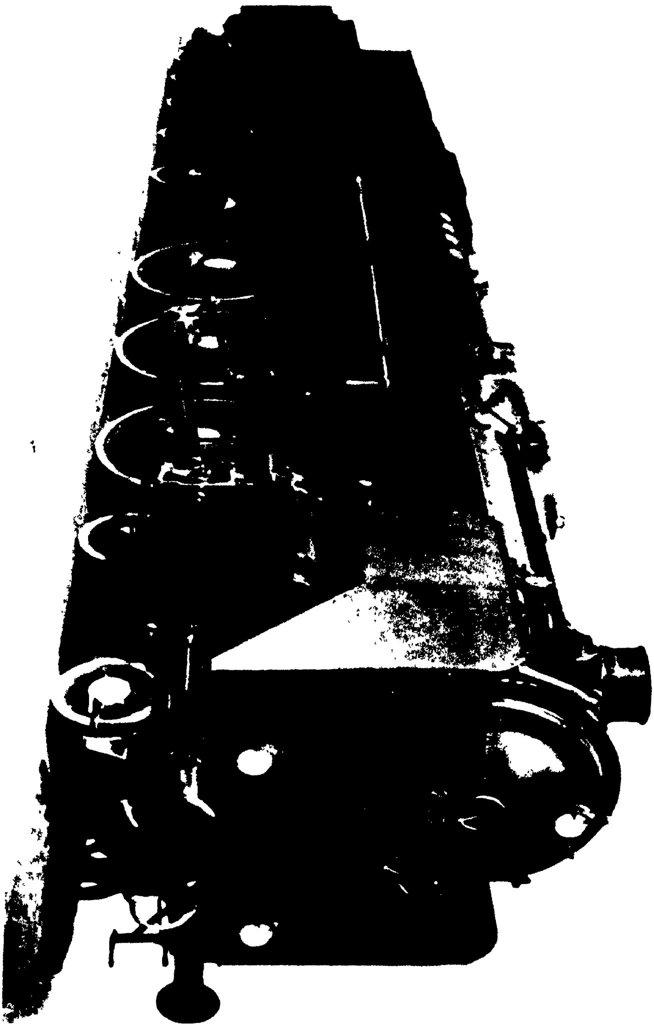
temperature of the chamber in which combustion is carried on shall be sufficiently high. To ensure this in the locomotive firebox, a brick arch is built above the firegrate, beginning under the lowest row of tubes, and inclined upwards towards the firedoor. In the kind of chamber so formed, combustion takes place, and the hot gases then pass round the arch, and so towards the tubes and through them to the smokebox. The fire itself rests on rows of cast-iron firebars, which are easily removable, and require frequent renewal. Underneath the firegrate is located the " ashpan," at the front of which are hinged steel doors, or " dampers," regulating the admission of air to the fire. Further air is admitted to the grate from above the fire level by specially-designed doors to the firehole, through which the fireman passes the coal on to the fire.

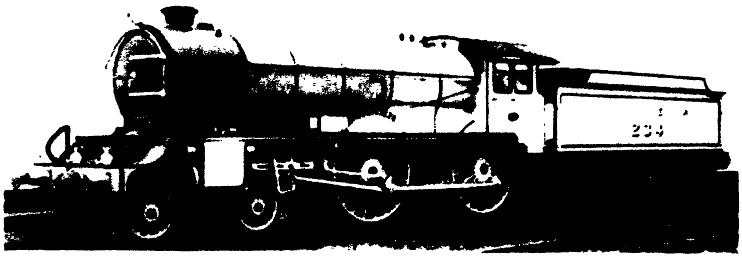
Before leaving the firebox end of the boiler, it is necessary to refer briefly to the fuel. As we have noticed previously, Great Britain is fortunate in having ample supplies of the finest coal that the world can produce. Of this the best for locomotive purposes is probably Welsh " steam " coal, which is the staple diet of Great Western locomotives, and helps in part to explain the remarkably low coal consumptions achieved on that railway. Other British railways encourage the collieries on their own systems, as far as possible; the London and North Eastern, for example, feeds its locomotives chiefly on various brands of Yorkshire coal. On the Continent the locomotives have to be worked on fuel of much inferior quality, often almost slack, and at other times dust compressed into the form of " briquettes," and the locomotive performance on many Continental lines, such as the French Nord, is the more remarkable when this handicap is taken into account. In the East of Europe, wood-burning locomotives are not uncommon, which require to be fitted with chimneys of great size and very singular

gotten, however, that the constant shaking received by the locomotive firebox in the course of its ordinary running is of no small assistance in the combustion of the fuel.

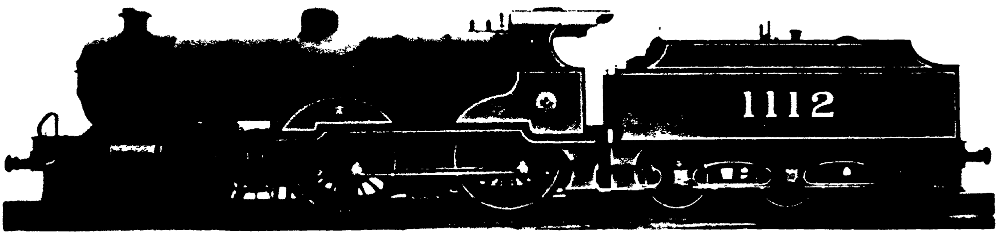
We have now to return for a time to the constructional details of the boiler. Openings must be made in the boiler for various purposes, the most important being the opening for the safety-valves. These are an essential part of boiler equipment, being intended to allow to escape any accumulated steam pressure in the boiler above that at which the boiler has been designed to work. In the early days of the locomotive, dead-weight safety-valves were the rule, and not a few burst boilers resulted from the fact that drivers had improperly overloaded their valves, to increase their steam pressure, and so to get more work out of their engines. Then came the day of the safety-valve controlled by springs, and later the statutory provision—which applies in the case of all boilers—that the adjusting nuts of the valves should be so sealed up as to make it impossible for them to be tampered with. Hitherto the commonest type of safety-valve for locomotives in this country has been the Ramsbottom type, with two parallel safety-valve columns whose valves are controlled by one central spring, together, generally, with a long handle projecting into the cab, so that the driver may by leverage allow the steam to escape more rapidly when the pressure becomes excessive.

But the Ramsbottom valve is now being replaced extensively by the "pop" valve, with its two independent columns of distinctive appearance. The name "pop" is descriptive of the explosive suddenness with which the valves lift, and then close again when the pressure has been reduced; and the special advantage of this type of valve is that it releases the surplus pressure immediately, whereas the Ramsbottom valve, although it begins to lift at the predetermined steam pressure, opposes so much





Si... ...L. N. E. R. (single expansion) (p. 141).



P. 79

L 157.

Midland Compound type, L. M. S. (double expansion) (p. 143).

British 3-cylinder 4-4-0 Express Locomotives (p. 113).

frictional resistance to the passage of the steam that the pressure in the boiler often rises well above this figure when the engine is " blowing off " hard. Conversely, the Ramsbottom valve does not close so promptly or so tightly as the " pop " valve, and may still be leaking when the pressure has fallen below the rated figure. It should be added that locomotive boilers are always tested hydraulically to a pressure 50 per cent. above that at which they are normally designed to work, before the engine goes into service.

Safety-valves are usually located over the top of the firebox, this being the part of the boiler in which steam generates the most rapidly. On the Great Western Railway, however, they are fixed on the middle of the boiler barrel, in the position usually occupied by the steam-dome, which on the engines of this company is dispensed with. It was often the practice in earlier days—the Drummond locomotives of the late London and South Western Railway are examples—to avoid a separate opening in the top of the firebox by affixing the safety-valves to the top of the dome, but this is seldom now done. Early Midland engines had an *embarras de richesse* in the matter of outlets for their boiler steam, being provided with safety-valves on their domes as well as above their fireboxes.

The dome of a locomotive boiler is the squat erection prominently located in the centre of the barrel. This outer covering encases a chamber which has been built on the top of the boiler, for the purpose of housing the regulator of the engine well above the water-level. In this connection it should be emphasized that the boiler is not filled with water to the top; there must be enough water amply to cover the top of the inner firebox, but above that space is left in which the generated steam may accumulate, it being highly undesirable that water from the boiler should pass down the steam-pipe in addition to the steam. Occa-

sionally a boiler is filled too full, with the result that water is carried to the cylinders, which is known as "priming." Any appreciable amount of water in the cylinders might result in the forcing off of a cylinder-end, so that it is then necessary to open the cylinder drain-cocks—resulting in the violent ejection of steam forwards from the cylinders that every reader has often witnessed—in order that the accumulated water may be forced out by the shortest possible route.

As mentioned in the last paragraph, the Great Western locomotive authorities dispense with a dome. Instead, they provide their boilers with fireboxes of considerable height, and taper the barrels upwards from the front to the back, thus providing what is claimed to be a better distribution of the steam space than that of an ordinary parallel boiler with dome. For the collection of steam from the boiler, a perforated pipe is provided transversely across the high front corner of the firebox. Domeless boilers are by no means new; the engines designed by Mr. Patrick Stirling for the late Great Northern Railway—including his famous "eight-foot singles" (Plate 8)—all had boilers which were bare of mountings from the chimney back to the safety-valve column, and had as characteristic an appearance as Great Western engines have to-day for the same reason. The idea of the omission is always the same; the less the number of openings in the boiler shell, so many the less steam-joints to keep tight and so many the less sources of weakness.

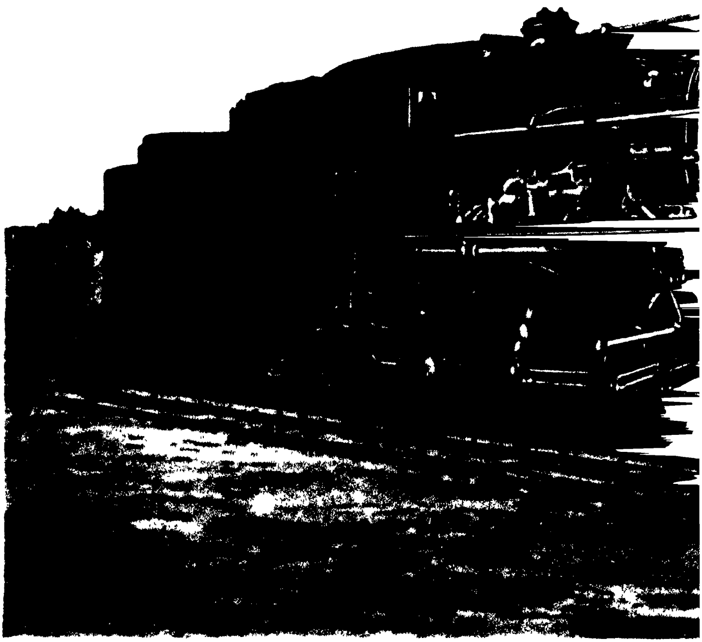
The regulator is the means whereby steam is admitted from the boiler into the steam-pipe, and so down to the cylinders. By his regulator handle in the cab, the driver is able to control the size of the opening in the regulator head, and in this way the volume of steam which is being used at any given time. From the regulator—situated, as

we have seen, in the dome of domed engines, but in the top front corner of the firebox, in Great Western domeless engines—the steam-pipe is carried along the top of the boiler, and through the front tube-plate into the smokebox. But in the modern locomotive it does not pass from there directly down to the cylinders, as there is next interposed the process of superheating.

The purpose of superheating the steam—or raising it to a higher temperature than that at which it was generated—is the transformation of the steam into a pure gas at a high temperature. Again, the moment that saturated steam is cooled, as is the case when it begins to expand in the cylinders, the accompanying fall in temperature immediately results in condensation, which may reach as high a figure as 20 to 30 per cent. of the total weight of the steam in an ordinary non-compound non-superheated engine. If, however, the temperature of the steam is raised before use to 600 or 650 deg. Fahrenheit, which is a usual figure, there is a considerable range of temperature in reserve before this condensation begins, so that almost throughout the stroke of the piston the steam remains "dry." Yet again, the effect of increasing the temperature of the steam by superheating even to 600 degrees, is to increase its volume by as much as 25 per cent. The advantage that results from superheating is thus two-fold; the loss of efficiency by condensation is practically eliminated, and the increase in the volume of the steam allows of the use of larger cylinders, with a proportionate increase in the tractive effort of the engine. In brief, the same weight of steam generated in the boiler can be made to perform roughly 20 per cent. more useful work than before. It must be remembered, at the same time, that the superheat flue-tubes occupy boiler space which would otherwise be devoted to ordinary tubes producing a greater volume of saturated

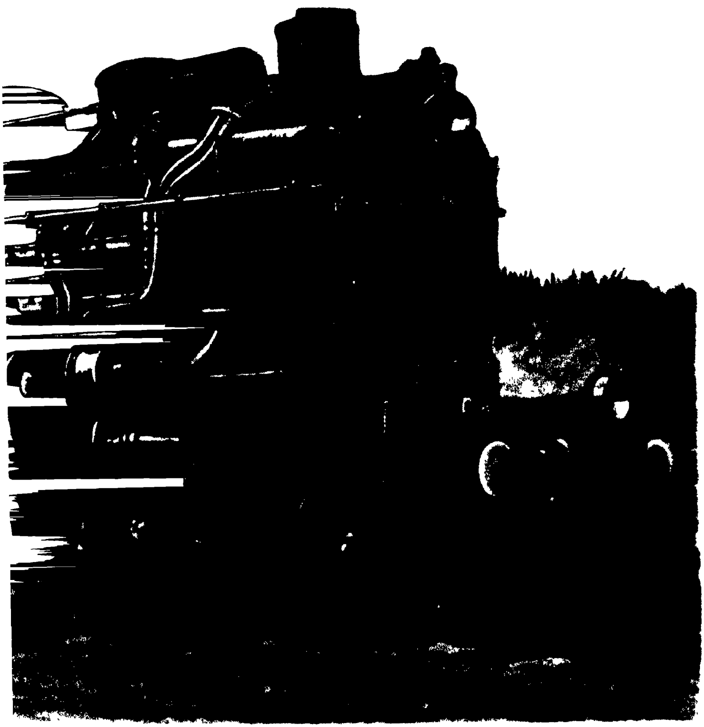
steam; consequently, there must be some increase in the heat transferred from the fire to effect the necessary superheat, and the actual saving effected is chiefly in water consumption. The first practical application of super heating to locomotives, made by the German Dr. Schmidt in 1898, so loudly commended itself by its results that the application of superheating to the locomotive boiler is now practically universal, in the case of all but shunting and other engines which are not in continuous steaming.

For the purpose of installing the superheating equipment, some of the top rows of tubes in the boiler are replaced by a smaller number of large flue-tubes, of $4\frac{3}{4}$ to $5\frac{1}{4}$ in. diameter. Across the mouth of these flues, attached to the front tube-plate, is arranged the " header," which is divided into two sets of compartments. Into the first set the main steam-pipe conducts the steam from the boiler. From each compartment the steam passes into two or three small superheater tubes, each of which is carried along the whole length of one of the large flue-tubes, then doubles back to the header, and after that makes a further double journey along a flue-tube before passing into the second series of compartments in the header. In the course of these journeys through the superheater elements, the hot gases passing through the flue-tubes dry the steam and raise it to a high temperature of superheat. The first set of compartments in the header therefore contains saturated steam, while the second set contains superheated steam, ready for use. The larger holes in the tube-plate for the superheater flues are seen in Plate 87. The general arrangement of flues, superheater tubes and header may be clearly followed in the locomotive section which constitutes Plate 61. In the earlier days of locomotive superheating, considerable difficulties were experienced in lubricating the cylinders and valves of engines which were designed



P. So

4-Cylinder Compound "Super-Pacific" (4-6-2) Ex



[illegible] M.

ocomotive, C de F. Du Nord, France [illegible]

Heating Surface, [illegible] sq. ft. [illegible] Grate Area [illegible] sq. ft. [illegible] Working Pressure [illegible] lb. per [illegible] of Engine and Tender [illegible] Tractive Effort [illegible] [illegible] lb. [illegible]

for its use. But these difficulties have been overcome by the substitution of high-class mineral oils for the previous vegetable oils, and by improved methods of lubrication, such as the force-pump lubricators of the Wakefield type, or vacuum condensation "sight-feed" lubricators of the Detroit type ; the latter have the advantage that they can be placed in the cab, under the driver's immediate notice, so that he can tell from the footplate whether or not the cylinders are being properly lubricated.

Another difficulty connected with superheating has been the tendency for the superheater elements, when empty of steam—that is, when the regulator is closed and no steam is passing to the cylinders—to burn, especially at the firebox end, where the heat is the greatest. The original Schmidt arrangement, to obviate this risk, was to close the mouths of the large flue-tubes with dampers, worked by a small steam cylinder prominently located on the outside of the smokebox, when steam was shut off, so that no hot gases should be drawn through them. Then followed the Robinson arrangement of circulating a small amount of steam through the elements, for the same purpose. But the present idea is mainly to use "snifting valves," which are generally located on the top of the smokebox, just behind the chimney, and when open cause a current of cold air to pass through the elements.

One minor fitting of importance in the smokebox is a steam-pipe of small diameter encircling the top of the blast-pipe. On the upper side of this ring are a number of holes or slits, so that the steam from the pipe may be thrown upwards in the form of a circular jet into the chimney. This is known as the "blower," and is for producing a draught for the fire when steam is being raised or when the engine is standing or running without steam. The blower is worked from the footplate, and its use in the last-

mentioned circumstances is of great importance, as otherwise the effect of the running of the engine with no exhaust up the chimney will be, instead, to cause a draught down the chimney, blowing the hot gases backwards through the tubes and then through the firehole door into the cab. Serious cases of burning have sometimes happened to engine-crews through forgetfulness of this simple precaution.

In conclusion of this chapter, brief attention must be given to the method of feeding the boiler with water. In the earliest days of the locomotive this was done by means of mechanically-operated feed-pumps—a method which had the serious disadvantage of only allowing the feeding to take place when the engine was actually in motion—but these have long since given place to the "injector," first devised in 1858 by the French scientist Giffard. In the injectors, which are usually arranged behind the foot-steps leading up to the cab, a jet of steam is made to issue from a nozzle at high velocity, combining in a second nozzle or cone with a jet of water from the tender tank. Part of the steam is condensed, and imparts its velocity to the water, with the result that the joint stream of water and steam has a greater velocity than the stream of water which would issue from any opening in the boiler shell under the influence of the steam pressure within. Through a suitable "clack-valve," generally mounted on the side of the barrel, the steam-jet is therefore able to perform the paradoxical task of forcing into the boiler a supply of water, against a pressure in the boiler equal to that of the jet itself. In Great Western locomotives, and in certain other British types, "top-feed" is employed; that is to say, the feed-water is introduced on top of the boiler, on the G.W.R. through the safety-valve opening.

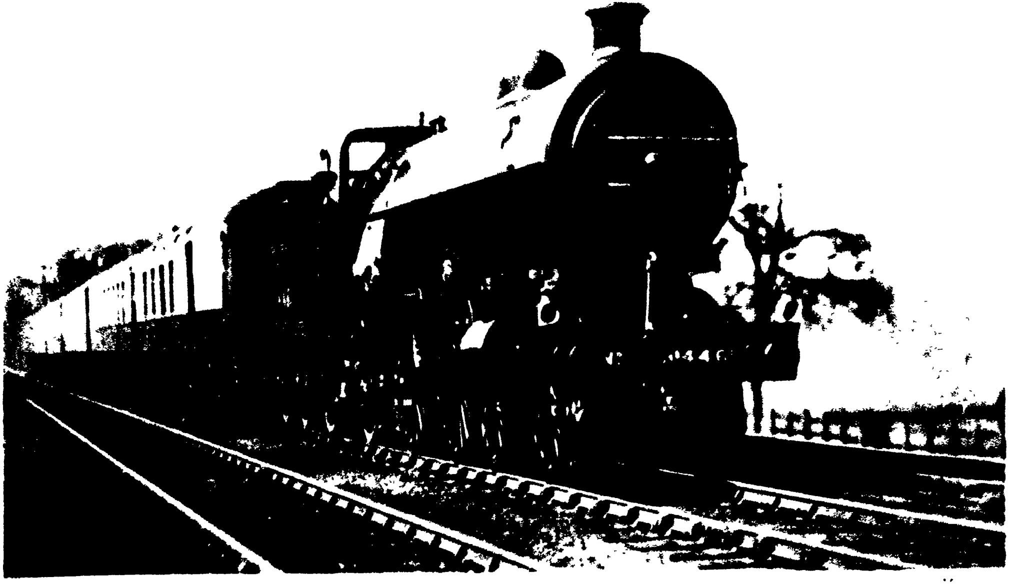
Modifications have been made in injector design from time to time, such as the use of exhaust steam instead of

live steam. Many locomotives are equipped for heating their feed-water, before introduction into the boiler, by the diversion of a part of the exhaust steam from the smoke-box into the water-tank for the purpose. Feed-water heating means that less heat is required in the boiler to convert the feed-water into steam, with resultant economies in coal consumption. The equipment usually includes a steam-operated feed-pump for the purpose of introducing the hot feed into the boiler. Feed-water heating has never been as popular in this country as elsewhere, but on the Continent it is commonly practised, the latest "Super-Pacific" express engines of the French Nord Railway, for example, carrying their feed-water heaters of the "A.C.F.I." type in a prominent position on the top of the boiler barrel, between the chimney and the dome.

Another circumstance in which feed-water becomes heated is in the case of a suburban tank engine fitted with "condensing" apparatus. The engines of such steam trains as still continue to work over the Underground lines—as, for example, the L.M.S. and L.N.E. suburban services working into Moorgate—have to condense their exhaust steam while working through the tunnels, in order to keep the stations free from smoke; this is done by carrying the whole of the exhaust steam through large external pipes, clearly seen along the upper part of the boiler of the L.N.E.R. suburban tank engine in Plate 56, from the smoke-box into the side-tanks. Condensing cannot, however, be carried on advantageously for very long periods together, owing to the fact that the diversion of the exhaust from the chimney practically does away with the draught.

As we have now concluded our study of the why and wherefore of locomotive design, it may not be in-

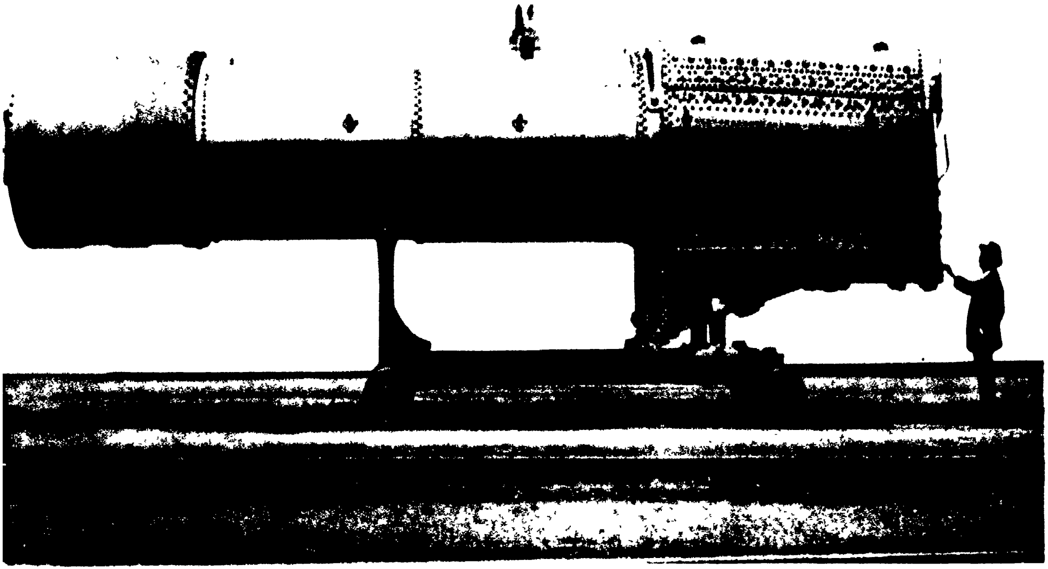
appropriate to refer to the table which constitutes Appendix F, and shows the principal dimensions of the leading express engines in this country. From this it will be seen that the most powerful British express locomotive type is the " King George V " 4–6–0 class of the G.W.R. (Plate 66), whose high tractive effort of 40,300 lb. represents a maximum drawbar pull of roughly 18 tons. Next in the list come the latest " Pacifics " of the L.N.E.R. (Plate 52), with 220 lb. working pressure, which have the distinction of being the heaviest express engines in the country; without tender each of these locomotives weighs 96¼ tons, and with the new corridor tender 158¾ tons. With their wide fireboxes these engines (with the corresponding 2–8–2 L.N.E.R. "Mikados") have the largest firegrates of any in the country, measuring in size 41¼ sq. ft. A study of this table will teach the reader much as to the general proportions usually followed in locomotive design. The premier place for power of all British types belongs to the L.N.E.R. " Garratt " locomotive, but this machine, with the three L.M.S. " Garratts " (Plate 60), the two L.N.E.R. " Mikados " (Plate 60) and the L.M.S. " Decapod " banking engine, is more or less experimental in character. The four types mentioned have tractive efforts of 32·6, 20·4, 21·0 and 19·3 tons respectively, and weigh 178, 149, 151¼ and 105¼ tons in working order.



Pl. 81.

The "West Riding Pullman" L.N.E.R., at full speed near Hadley Wood (p. 2[illegible])

Ivatt "Atlantic" Locomotive No. [illegible] (pp. [illegible])



M/ 165

No. 6 Standard Boiler, used on "King" Class Locomotives, G.W.R.

[illegible] The safety valves are

CHAPTER IX

The Steam Locomotive—At the Shed and on the Road

In the three preceding chapters we have followed the construction of the locomotive, and have examined the reasons for the various features characterising its design. We have now the still more interesting task of passing with it on to the road, and noting the way in which it is handled by the engine-crew, as well as the methods by which it is cared for in the running-shed. Immediately after completion, and before the engine has received its final livery of paint, it is the practice on some lines to take it for a "trial trip" for a short distance down the line from the locomotive works, and back again. During the run of 20 miles or so, no attempt is made at high speeds, but a number of men are detailed to hang on all round the engine, from this precarious point of vantage drenching all the mechanism with oil, and seeing that no part of the sliding or rotating parts run hot. The final painting is then carried out, and the engine is ready for service. Work under the easiest conditions must follow for some time, while the mechanism is getting into thorough running order, and the locomotive is then drafted to the particular duties for which it has been designed.

For this purpose it is attached to a "shed." The engine-shed is in reality the "stable" of the locomotive, where the "iron horse" receives the attention that enables it to keep in efficient working. The ideal condition is that every engine should return to its shed once in every

twenty-four hours—by night or day according to whether it is on day or night duty respectively—for cleaning and examination, and, if necessary, for repairs; but shunting engines are frequently absent from the shed for a week at a stretch. The *personnel* of the shed consists of the mechanics who carry out what are called "running repairs"—that is to say, the minor operations of repairing, major operations requiring the engine to be withdrawn temporarily from service and returned to the locomotive works—a number of cleaners, from whose ranks are recruited the drivers and firemen of the future, and, of course, the drivers and firemen themselves.

The work of each locomotive at a shed throughout the week is very carefully plotted out into "rosters"; that is to say, each engine is arranged to work a certain definite sequence of trains from the beginning of the week to the end. During the currency of any one time-table—the winter service remains more or less unaltered from October round to May or June, the augmented summer service operating for the remaining three months—these rosters are kept more or less "standard." The various rosters are grouped together, according to their relative difficulty, and the drivers and firemen themselves are formed into "links," according to their experience and ability, each link being responsible for the manning of one group of the rostered workings. On graduating from a cleaner into a "passed fireman," the novice enters the lowest link, working on shunting engines; from these he passes by degrees to freight engines, then passenger engines, then express engines, and last of all to the coveted "top link" at the shed, which embraces all the most responsible but most remunerative express duties. The next stage is that of graduation from "passed fireman" to "passed driver," when all these varied stages must be passed through again,

ere—perhaps twenty years or so after cleaning days—the driver of such an express as the "Cornish Riviera Limited" or the "Royal Scot" or the "Flying Scotsman" is first entrusted with the task of driving so important a train. The only country in which a third man is carried regularly on the engine is India, where for the menial work of the footplate an assistant of the lowest, or "sweeper," caste is employed. He may be seen in front of the cab in the photograph of an Indian freight engine which forms Plate 83.

There are no short cuts to the command of the footplate, and rightly so. The driver has to be perfectly familiar with every yard of the road over which he travels. He must know the position and the steepness of every gradient, and the demands that they are likely to make on the engine, as well as the way in which, by the manipulation of his regulator and valve-motion, to make the best use of the steam produced by the labours of his fireman. His ear must be trained to detect the slightest irregularity in the "beat" of his engine, which might tell him of some defective or damaged part. It is while acting as a cleaner, at work over all parts of the engine, both internal and external, that the future driver obtains his first knowledge of locomotive construction; during the years of firing he is acquiring first-hand information as to the management of the engine, the production and the use of the steam, and the characteristics of the various lines traversed; and so he passes to driving with a mine of varied experience at his command, further increased by the systematic instruction given by the railways in specially-equipped instruction cars (Plate 88).

We have now to study the handling of a locomotive, which is best done by accompanying the crew on one of their daily turns of duty At a definite time before the

departure of the train they are detailed to work, the crew present themselves at the shed, and " book on " for duty. The driver's first task is to consult the notice-board, as there may be exhibited special notices affecting the line over which he is to run, such as temporary restrictions of speed owing to track repairs or engineering works, or alterations to signals. A special " weekly working notice " is issued to all those concerned with the working of the trains, drivers included, detailing the more important of these warnings ; and further reminders of speed restrictions, both temporary and permanent, are given by special line-side indications ; the shed notice-board is intended more particularly for changes which have to be brought into operation at short notice. The crew now pass to the shed-road on which their engine is standing, and find it with steam raised to a pressure of 100 lb. or so.

A special allowance of time is made to the driver and fireman, before the booked departure time of their engine from the shed, to enable them to make certain necessary preparations. These preliminaries include, first of all, the withdrawal from the shed stores of the supplies of oil, waste and other requisites for their day's journey. Then must follow a thorough examination of the engine and its mechanism, during the course of which the driver has to satisfy himself that the various parts are in proper adjustment, to charge the different lubricators with oil and to arrange the trimmings ; the fireman will make up the fire, clean the footplate of the mess left by the firelighters, see to it that the tender is fully supplied with coal and water, and, among other minor but none the less important tasks, that the sand-boxes of the engine are filled with dry sand. For lack of the last-mentioned precaution many a train has been brought to a stand on a rising gradient, when the rails have been greasy with moisture, or has experienced

difficulty in starting, with consequent loss of time, owing to the driving wheels of the engine slipping round on the rails.

At a certain definite time the engine is run "light" from the shed to the station at which the train-working is to be taken over, sandwiched in between the ordinary trains; and if the line concerned be congested with traffic, a number of engines thus going on duty may be run together in an imposing array, in order that the line may not be needlessly occupied by a number of independent locomotives. On coupling up to the train—an operation usually performed by the fireman—the driver is informed by the guard as to the weight of the train behind him; this is, of course, an important piece of information, as it will largely regulate the driver's method of working his engine. The custom now is to reckon a train, not by the number of vehicles, which gives only an approximate idea of its weight, but by the actual weight of the coaches. This, as may be seen in Plate 112, is marked on the ends of each coach, and is thus readily ascertainable. Such weights are only "tare," or empty weights, but the addition of passengers and luggage in a corridor train, even if it be crowded to repletion, cannot exceed a maximum of about 10 per cent. of the empty weight of the stock; 5 per cent. is a more normal figure. Non-corridor stock, when full, can hold passengers up to 20 per cent. of its tare weight. Accurate reckoning of a freight train load is a matter of considerably greater difficulty; in this case the number of "full" or "empty" wagons is usually reckoned, with special allowance for wagons or exceptional size or weight, but even so there is room for a large margin of error in any reckoning of the gross weight of the train.

It should be remarked here that most companies have certain definite limits as to the maximum loads which may

be hauled by each different type of engine on the various timings. The faster express timings, both passenger and freight, need the more drastic limitations of train-weight, if time is to be kept. Any likely excess over normal loads is generally known in advance, so that suitable preparation may be made by the provision of an assistant, or " pilot " locomotive. Occasionally, however, extra coaches have to be added at the last moment, in consequence of an exceptional rush of traffic ; to meet such contingencies as this, as well as possible failures of engines, it is the custom, at terminal stations and other important traffic centres, to maintain a locomotive in steam permanently, called the " pilot," for such emergency duties as these. When two engines are thus attached to a train, control of the braking is vested in the leading driver, who has the better look-out of the two, though the driver of the second is in no way relieved of the necessity of keeping a careful look-out ahead. It is for this reason that the assistant engine is often attached next the train, with the train engine in front, so that the more experienced driver may be in control.

Not infrequently it happens, of course, that such locomotive assistance is not available in abnormal circumstances, with the result that the crew have to make the best of a bad job, and run their excessive load unassisted. There is excuse for lost time in such circumstances, but more often than not, by remarkably skilful firing and driving—such as nothing but a lengthy experience can make possible—the overloaded engine is coaxed to perform such abnormally hard work that time is maintained. To-day the tendency is to build locomotives of such power that on most of our main lines it is becoming rare to see a " double-headed " train. On some occasions the sight of a second engine at the head of what may appear to be but a moderate load is

merely an indication that one of the engines is being worked home to its shed, and that this is the most useful way in which it can make the journey, with the additional advantage of not congesting the line concerned with an independent "light engine" working.

But we must return to the footplate. An important operation, prior to starting a passenger train, is to test the brake, after the engine is coupled up. The modern "continuous" brake in use on passenger stock puts it in the driver's power to apply the brakes on every wheel throughout his train; without such means of making a rapid stop, indeed, it would be highly dangerous to run trains at the high speeds which obtain to-day. Two diametrically-opposed types of brake are in general use; the "Westinghouse," in which the medium of application is compressed air, and the "automatic vacuum," which, as its name implies, depends on the destruction of a vacuum in the brake cylinder for its application. Through many years of railway history the relative merits of the two systems have been hotly contested, but no final decision has yet been reached; in this country the automatic vacuum brake is in use on the Great Western and Southern Railways (the Westinghouse equipment of the Central Division is, for uniformity, being replaced by the vacuum), as well as the major part of the L.M.S. system; the L.N.E.R. is divided between the vacuum brakes of the Great Northern and Great Central sections and the Westinghouse brakes of the North Eastern, North British and Great Eastern sections.

All vehicles intended for through running have to be equipped with both systems of braking, as well as a certain number of locomotives; for use on "dual-fitted" engines, an ingenious brake ejector has been devised which at the same moment apples one brake on the engine and the

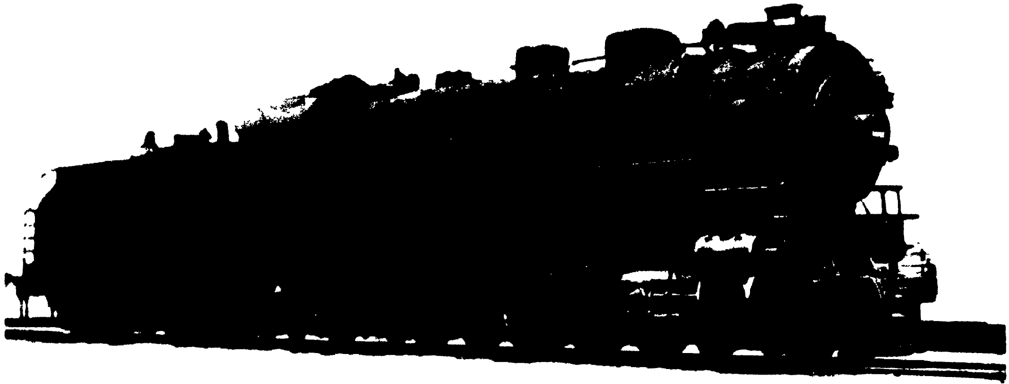
other on the coaches of its train. Engines fitted with the Westinghouse brake can be distinguished by the fact of carrying an air-compressor, or donkey-pump, on the side of the boiler, which puffs incessantly when the engine is standing. Vacuum-fitted engines, on the other hand, exhaust the necessary vacuum by means of a steam-driven ejector, the roar of which may be heard when the engine is standing, often supplemented by a vacuum-pump, driven off the engine cross-head. The latter is a standard equipment on the Great Western Railway, and explains the characteristic "ticking" of Great Western engines when they are at work. In these days many goods wagons are vacuum-brake fitted, in order that perishable traffic, such as foodstuffs, may be carried at high speeds; ordinary goods wagons, however, are fitted with hand-brakes only, which cannot be worked when the train is in motion. The driver of a slow goods train, therefore, has to rely on a steam brake on his engine, and on the hand-brake in the guard's van at the far end of his train, applied by the guard, in order to bring his train to a standstill, which, with heavy loads, is necessarily a slow business.

On the signal to start being given by the guard, the driver, whose position in the cab is seen in Plate 89, opens his regulator. As a preliminary, he has probably put the engine in "full forward gear," in order to make use of the maximum cut-off possible in the cylinders. The regulator will be opened gradually at first, as a sudden opening to the full may cause the engine to slip, as well as giving an uncomfortable shock to the passengers in the train. The gradual opening is still more important in working freight trains; the driver of a long freight train will see to it in stopping that the wagons come to rest with the couplings slack and the buffers touching, so that in re-starting he may pull the couplings taut one by one, and so bring the load

Pl. 83. *M* 172.

2-10-0 type Freight Locomotive Great Indian Peninsula Railway

(5 ft. 6 in. gauge)



F. 54 M 173.

Oil-burning 4-10-2 type Freight Locomotive, Southern Pacific Railway, U.S.A. (p. 155).

gradually on to his engine; too energetic a start, in these conditions, would probably result in broken couplings. If the driving-wheels of the engine slip round on the rails, on the application of steam, dry sand is applied, either falling by gravity on to the rails ahead of the leading pair of "drivers," or blown right under them by means of a steam jet; the sand may, indeed, be applied in any event as a precautionary measure, as slipping is bad for the mechanism of the engine.

As the engine is getting under way, the cut-off is brought back gradually from the 75 per cent. or so of full gear to the running position, which varies according to the type of road over which the engine is running, a longer cut-off being used for uphill work, and a shorter for running on the level and downhill. The relative merits and demerits of running with long and short cut-offs have already been discussed in Chapter VII, but the essential fact may be repeated that the engine which is capable of being driven with regulator wide open, and with the cut-off brought well back—as, for example, the cut-offs of 20 per cent. and even 15 per cent. common in the running of the latest British types of express engines, even with fast and heavy trains—is likely in the end to make the most efficient use of the coal which has been burned to produce its steam. It is an education to watch a really competent driver, varying his cut-off to suit each different change of gradient, applying his mind to the problem of getting the very best possible work out of his engine, in addition to the essential task of an unceasingly watchful scrutiny of the signals and the road ahead. On other footplate trips one may see a driver, once he is well away from the start, fix his cut-off in one running position, and make the whole of the variation in steam supply necessary to negotiate up and down gradients at the proper speeds by means of his regulator

opening alone ; but this method has little to commend it in comparison with the proper use of the expansion gear. The work of " top-link " drivers is, indeed, a highly scientific business, and one's admiration for the cream of British drivers is the greater in that practically the whole of their skill and wide experience is self-acquired, rather than the product of systematic tuition.

Firing a locomotive again, is far from being merely the work of a navvy. On any heavy express run the fireman may have to transfer coal from the tender into the firebox at the rate of a ton an hour, and even then the work is very much more than that of merely shovelling the fuel from one into the other. The art of firing consists in producing just the right quantity of steam at just the right moment ; more, when hard work is ahead, such as travelling up a long or steep gradient ; less, when the engine is faced with a spell of easier running. In order that combustion may be even and thorough, the actual placing of the fuel in the firebox must be done with great care—so much at the sides, so much at the front, so much immediately under the firedoor—the fireman needing to apply his mind as thoroughly to the science of firing as the driver applies his to that of driving.

The fireman's glance will be frequently directed towards the pressure-gauge of the engine, in order that he may see that his firing is maintaining the working pressure at its proper level, but no more ; excess of steam blowing off from the safety-valves, and thus entirely wasted, is no advertisement for the fireman, though at times it cannot be avoided. The level of the water in the boiler is also in the fireman's care ; on long runs, when the engine is working hard, it is often the practice to keep one injector in continuous working, the other being put on or off as more or less water may be required in the boiler. Even the feeding of the boiler with water requires caution ; a sudden influx of

cold water just when a stiff up-grade is approaching, for example, may lower the boiler temperature, and with it the pressure, just when the latter is most needed. The actual water level is indicated by a couple of "gauge-glasses," one on each side of the firebox front, the crew being protected from possible breakage by an outer case of thick glass. Care must be taken that the boiler is not filled too full, for an overfilled boiler will cause "priming," or the carrying of water from the boiler down to the cylinders, as was explained in the last chapter; neither must the water-level be allowed to fall so low as to uncover the crown of the firebox, as such an eventuality might result in a burst boiler. A plug of some readily fusible metal is usually fitted in the firebox crown, so that the last-mentioned possibility may be guarded against by the fusing of the plug, and a rush of steam into the inner firebox, which warning would give time to release the steam and draw the fire before the firebox crown collapsed.

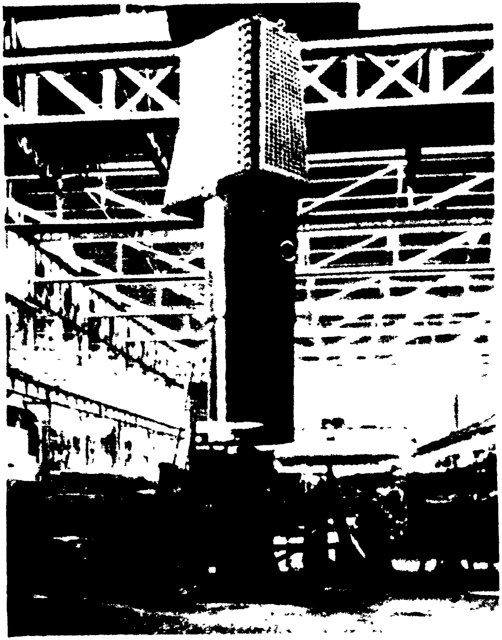
Considerable differences of opinion have hitherto existed among railway authorities as to whether an engine should be driven from the right-hand side (looking forwards from the cab) or from the left. Many railways up till now have favoured the right-hand position, as this has given more room for the fireman to swing his shovel round in a right-hand direction from the tender to the firehole door. But in these days of enormous boilers, and high Belpaire fireboxes, the view from the right-hand side of the engine to the left of the track, where the majority of the signals are located, is becoming so restricted that there is a general tendency towards the substitution of left-hand drive. Many large modern engines, however, have certain details of their operating gear duplicated on both sides of the cab; a double-ended regulator handle, for example, is often fitted, and is of considerable help to a driver in shunting,

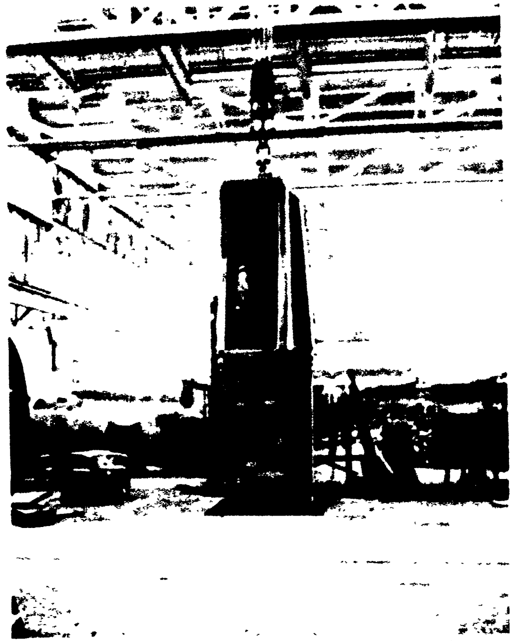
or at other times when it is necessary for him to look out on both sides of the engine. The equipment of a modern locomotive cab is shown in the fine photograph which constitutes Plate 86; this is accompanied by a numbered key diagram (Fig. 17) indicating the purpose of each control.

Trouble in the matter of look-out is occasionally caused by exhaust steam "drifting" from the short chimney of the modern express locomotive—especially in these days of short cut-offs and a soft blast—across the front windows of the cab. In Germany this is obviated in the latest express locomotive designs (Plate 78) by wind-deflectors at the front of the engine, designed, when the engine is running at speed, to make a strong up-draught of air, and so to lift the exhaust steam clear of the cab. These wind-shields have recently been fitted to some of the "King Arthur" class express engines of the Southern Railway (Plate 92), with excellent results.

As we have seen at the beginning of this chapter, the engine rosters are planned, as far as possible, to enable the engines to return to their sheds once during every twenty-four hours for cleaning and attention. On many of the long non-stop runs of to-day, and in freight working, however, this is not possible, and the engine is then temporarily accommodated at the locomotive shed nearest to the destination station, returning to its own shed the following day. The crew is similarly boarded away, comfortable hostels being provided for this purpose in connection with most of the chief running sheds.

In this connection it should be remarked that, although the working hours of the crews have to be kept down as nearly as possible to the statutory maximum of eight per day, there is no such protection for the locomotive. A considerable waste of locomotive power would be involved,





Pl. 85.

M 179

Boiler suspended over riveting machine

Underside of boiler, showing inner firebox

"King" Class Boilers in Boiler-Shop, Swindon Works, G.W.R. (pp. 150, 152)

Cab of King Class Locomotive, Great Western Railway

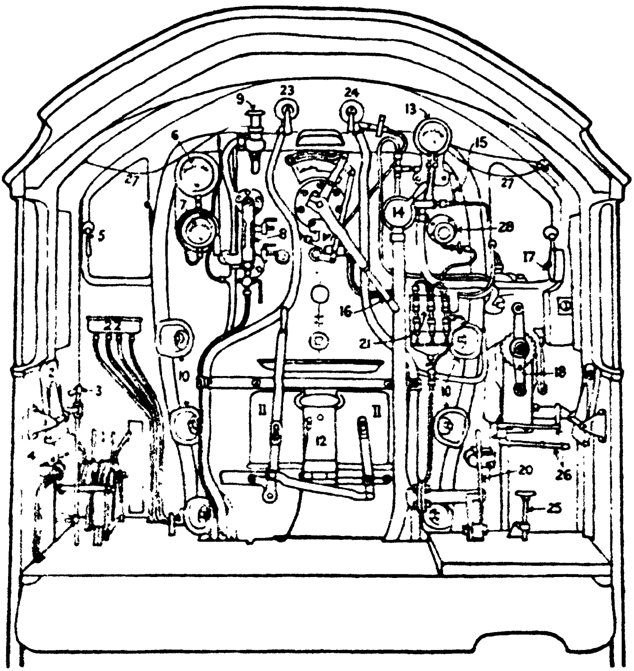


FIG. 17.—CAB OF "KING" CLASS EXPRESS LOCOMOTIVE, G.W.R.
Key to Controls.

1. Damper controls.
2. Fireman's tip-up seat.
3. Exhaust Steam injector water regulator.
4. Cock for watering coal.
5. Spectacle glass wiper.
6. Steam pressure gauge.
7. Carriage-warming steam pressure gauge.
8. Water-gauge.
9. Carriage warming automatic steam-valve.
10. Wash-out plugs.
11. Fire-hole doors.
12. Fire-hole flap plate.
13. Vacuum brake gauge.
14. Ejector air-valve for vacuum brake
15. Ejector steam-valve for vacuum brake.
16. Regulator handle.
17. Automatic signal repeater bell.
18. Reversing motion screw control.
19. Driver's tip-up seat.
20. Cylinder cocks control.
21. Vacuum sight-feed lubricator (cylinders and piston-valves).
22. Lubricator for axle-boxes, etc.
23. Exhaust injector live steam cock.
24. Right-hand injector steam cock.
25. Right-hand injector water cock.
26. Sanding gear controls (forward and backward).
27. Whistle control.
28. Steam blower-valve.

indeed, if every locomotive were worked for no more than eight hours out of the twenty-four. The majority of locomotives are, therefore, double-manned ; that is to say, they are worked by at least two different crews during the course of each day. On the non-stop London-Edinburgh run of the London and North Eastern Railway, which extends over 8¼ hours, and is regarded as too exhausting a responsibility for a single crew, this double-manning is in force, engine-crews being changed at the midway point by means of an ingenious corridor down one side of the tender (Plate 90), which is vestibuled to the front coach of the train. At the midway point on the journey, the relieving crew, who until then have been travelling comfortably in the front compartment of the train, walk through the vestibule and the tender corridor on to the footplate, the crew previously in charge passing back to the reserved compartment for the remainder of the journey.

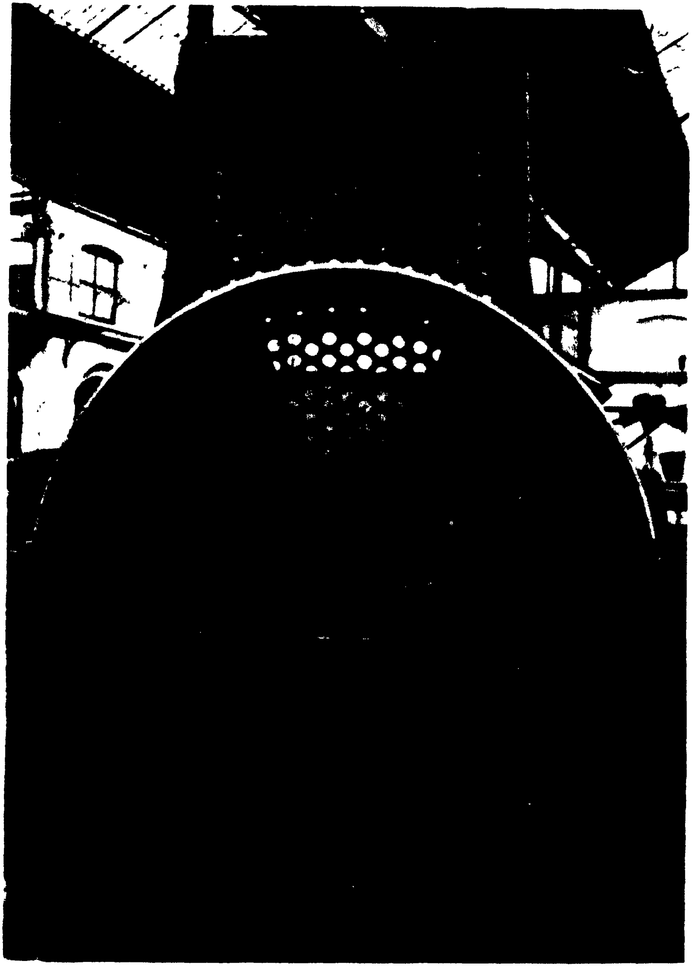
Multiple-manning of engines is even more essential in freight working than in passenger, and any one freight engine may come under the control of a number of different crews during the week ; but with passenger engines, and especially those of the latest and largest types, efforts are made to confine the working of each engine, as far as can be managed, to not more than two crews. It is only natural that considerably more care should be taken of a locomotive when the crew or crews can regard it as "their own," and this factor has a considerable bearing on the reduction to a minimum of locomotive maintenance costs. In earlier days, when hours were longer, and it was usually possible to allot the working of each engine to an individual crew, the affection of an engine-driver for his mount was often no whit less than that of a rider for his horse, and his care for the condition of his locomotive was correspondingly great.

At the close of their working day, the crew either hand over their locomotive to the crew detailed to relieve them, or, if the engine's labours for the day are also at an end, to the running shed. In the latter case, the fireman will have let his fire get as low as possible, in order to expedite the work of cleaning the firegrate, ere the engine is handed over to the shed staff. Before booking off duty, the driver reports any irregularities he may have noticed in the working of the engine, or any repairs that he may consider necessary, in order that these may be attended to before the engine goes again into service.

The first attention to the incoming locomotive at the running shed is probably coaling, and it is moved under its own steam to the coal stage for this purpose. In many of the larger sheds elaborate coaling plants (Plate 93) have now been installed, in order to reduce to a minimum the time and labour of replenishing the tenders with fuel. At the same time, or immediately after, the accumulation of fine ash is removed from the engine smokebox, automatic plants, worked by compressed air, being also in use at certain depots for this purpose. The next job is to rake out the fire. If the engine is required in service again after a few hours only, the fire is merely cleaned by the removal of the clinker, with a long-handled shovel, through the firehole door, the ash being raked also out of the ashpan. Otherwise the fire is dropped completely. An important task follows next in the removal of the accumulated deposits of soot, which is a bad conductor of heat, from the boiler tubes; this is done by blowing a powerful jet of steam through each tube, the work being assisted by the use of a wire brush at the firebox end, where the deposits are thickest, and a long wire rod, tipped with a swab, for the purpose of loosening any accumulations further along the tubes.

The engine is then passed into the shed (Plate 94), where inspection pits, arranged between the rails, allow the shed fitters to conduct a thorough examination of the motion. Minor casualties receive immediate attention; heavier repairs (or adjustments) require that the engine shall be "stopped," or temporarily withdrawn from traffic; still heavier repairs or renewals, such as the replacement of a boiler, compel the return of the engine to the works. Such changes, of course, call for the provision of substitute engine power, and entail a constant exchange of engines between running sheds, the "population" of any one shed rarely remaining the same for long periods together. There are certain regular examinations also which require the temporary withdrawal of engines from service; water and pressure gauges, brake-gear and smokebox are thoroughly examined each month; boilers have a monthly examination by the shed staff, a half-yearly one by a headquarters inspector of the running department, and a very stringent test, at least once annually, to prove that the safety-valves are properly adjusted. Cylinders and piston-valves must be opened up for examination at least twice a year, and more often still in the case of express passenger engines.

Every week, where practicable, the boiler of each engine is washed out. The collection of fur and scale on the outside of the boiler-tubes is as disadvantageous to steam production as is the presence of soot inside them, and regular removal is therefore vital. Hot water under pressure is introduced through suitable plugs in the upper part of the boiler, at the rate of 40 gallons or so per minute, and specially-arranged "mud-holes" on the underside of the boiler allow of the removal of the accumulated deposits. To help in the loosening of the scale, rods are introduced through the openings last mentioned, and are scraped vigorously over the boiler surfaces. The boiler-smith



Junction of Barrel and Belpaire Firebox. "King" Class Locomotive Boiler, G.W.R.

E. 88 N 181

Enginemen's Instruction Car London & North Eastern Railway (p. 767)

then takes the opportunity of examining the inside of the boiler, with the aid of a portable lamp and small mirrors, and after he has pronounced it to be in satisfactory order, the plugs and mud-hole doors are tightly screwed up, and the boiler can be re-filled. Hot water is usually employed for refilling, in order to reduce the time needed for raising steam.

The next operation is that of cleaning. Less attention is paid in other countries than in our own to this important part of locomotive maintenance, and for many years after the war the high cost of labour resulted in a considerable falling off in the attention paid to locomotive cleaning in Great Britain. Freight engines seldom get the same attention as passenger engines in this respect, but proper cleaning of the latter has now been resumed on all British lines, the sound advertising value of a spick-and-span exterior, in these days when the railways are the subject of much public interest, being fully realized. Application of oil and water, aided, when necessary, by bath-brick, removes from all the exposed parts their coating of dust and grime, and polishing with oily waste completes the cleaning of the motion and the paint-work. Last of all the fire, if it has been completely dropped overnight, requires relighting; this is done by means of a shovelful or two of coal from the shed furnace, or by the use of bundles of firewood cut up from old sleepers. Raising steam may require from three to five hours, according to the size of the boiler, and the "lighter-up" at the shed is responsible for seeing that each engine is ready for the road, with steam up, at the time required.

Engine-sheds vary considerably in size, according to the number of engines that they are required to house. In some country districts shed room for a couple of engines or so will be ample accommodation; at busy traffic centres, on the

other hand, the "stud" attached to one running shed may amount to a hundred locomotives or more. Opinion is divided as to the relative merits of the "round-house" (Plate 94) or the rectangular shed with parallel roads; the former, with all its tracks radiating from a central turn-table, facilitates the removal of an engine from any position in the shed; the latter has the advantage of taking up less space. Good lighting, a plentiful supply of water, efficient arrangements for carrying smoke and steam away through the roof, and inspection pits between the rails, are essentials at every shed. Generally speaking, the larger the shed, so much the more extensive its equipment, so that some of the largest running sheds are able to undertake heavy repairs which the smaller sheds must remit to them when necessary. Cases of "general overhaul" must be passed to the chief locomotive works for attention.

The running shed foremen of the larger sheds are entrusted with one important duty which, at first sight, might appear to lie somewhat outside the scope of their activities. It is the clearance of the line after an accident or a breakdown. Vans, equipped with all the tools that may be required, are kept in constant readiness, and the largest depots have their own powerful steam-cranes, designed in such a way that, with lowered jib, they can be run to any part of the line (Plate 95); a certain proportion of the shed staff is specially trained for this duty; and at any hour of the day or night, on receiving telegraphic or telephonic information of a breakdown or other mishap involving blockage of the line, the shed foreman and his staff must be prepared to turn out with the "breakdown train." The first available engine in steam at the shed is requisitioned; the breakdown train is given precedence over all other traffic; and the foremost duty of the breakdown gang is, at all costs, to clear the line and restore the interrupted communication.

Before we leave the design and working of the steam locomotive, it is necessary that we should review briefly the methods of experiment which are followed in order to ascertain, as far as possible, whether or not it is performing efficiently the duties for which it has been designed. Efficiency in performance, as the last two chapters should have made clear, goes far beyond the mere ability to move a train of a given weight at a certain scheduled speed. This is the primary requisite, in locomotive design, but it is of little less importance that the work shall be carried out at a minimum cost in both fuelling and maintenance. To the locomotive engineer, therefore, the consumption of coal necessary to maintain one horse-power at the drawbar per hour—the most satisfactory of all bases of comparison, as between one locomotive type and another—is as important a line of investigation as the speed at which it can run and the loads it is capable of hauling.

The most elaborate of all the apparatus used in such tests is the dynamometer car, of which typical interiors are seen in Plate 98. This specially-designed vehicle is maintained for testing purposes alone, and for the purpose of testirg is coupled up between the engine under test and the train. The drawbar of the dynamometer car pulls against a powerful system of springs under the coach, actuating a pen which graphically records the drawbar pull on a large roll of slowly moving paper. Other pens are employed to mark on the roll times, distances, and various details connected with the working of the engine, and there are ingenious instruments which automatically add up the total work that is being done by the engine, and enable the drawbar horse-power to be calculated at any point of the journey. Thus the roll, at the conclusion of the trip, embodies a mass of valuable information.

Other experiments are carried out on the engine itself.

Of these the most informative is known as "indicating"; this is a test as commonly applied to the stationary as to the locomotive steam engine. A small cylinder is connected by a tiny steam-pipe directly with the interior of the locomotive cylinder; attached to the piston-rod of the cylinder is a pencil which, when the connecting cock is opened, rises and falls with the rise and fall of the pressure in the cylinder during each completed revolution of the driving wheels. The pencil, in its movement, is made to describe a diagram, in the form of a boot, on a small roll of paper which is rotated to and fro, in correspondence with the movement of the piston in the cylinder, by an arm direct from the crosshead. Thus the diagram affords an exact picture of the work of the steam in the cylinder, the expansion of the forward stroke and the compression on the return stroke, in particular, being clearly indicated. From the indicator diagrams it is readily possible to calculate the cylinder or "indicated" horse-power of the engine under all conditions of working.

A further line of investigation concerns the smokebox; by suitable apparatus connected with the interior of the smokebox, the vacuum produced by the blast can be measured, and samples of the smokebox gases taken from time to time for analysis, in order that it may be seen whether potential sources of heat are being thrown, unused, out of the chimney with the waste gases. To protect those who are entrusted with the breezy task of carrying out these investigations, a shelter of timber or steel-plate is built round the smoke-box of the engine, in appearance like an additional cab at the front end (Plate 99), which by its prominence advertises the fact that this testing is being carried on.

Dynamometer car tests and indicating are frequently carried on at the same time. For this purpose electric

bell communication is arranged between the indicating shelter and the car, and from the engine cab to the car, so that the exact points where indicator diagrams are made, or observations taken in the cab of changed positions of regulator and reversing gear, may be duly marked on the large roll. It is also the practice now to establish communication direct from the engine smokebox into the dynamometer car, so that the exhaust gases can be brought at any moment into the car, and analysed on the spot. Careful note is taken of coal and water consumption, as well as various other details connected with the engine working. Such investigations as these are, of course, costly, as they require the whole time of a staff of at least five observers, as well as the running and maintenance of the special dynamometer car and other apparatus; and for this reason they are usually confined to tests of new or altered locomotive types only. But there is no doubt that they are of great value, and have strongly influenced the course of British locomotive design during the last few decades.

Experiments of a different character have been made from time to time by the exchange of locomotives between different companies for the purpose of trial over each other's lines. It is difficult to convince the newspapers and the public that such exchanges are in the nature of scientific investigations rather than sporting contests, with the result that the somewhat embarrassing publicity accorded to these events is a serious deterrent to what might otherwise prove an admirable exchange of ideas. This was particularly the case with the famous exchange of 1925, when the Great Western Company exchanged their 4-cylinder 4-6-0 engine "Pendennis Castle" for the London and North Eastern "Pacific" engine "Victor Wild." Public interest in these trials was the more keen

in that the two types had been exhibited side by side at the Wembley Exhibition of the previous year. Each engine succeeded in carrying out, without difficulty, the tasks usually allotted to the other; but the smaller and lighter Great Western machine proved its higher efficiency by burning the less coal of the two types.

Amongst other important exchanges the Great Western has figured in two of some note. In 1910 the 4-cylinder 4-6-0 G. W locomotive "Polar Star" went over to London and North Western metals in exchange for the considerably smaller L. & N.W. 4-6-0 engine "Worcestershire," of the "Experiment" class; here the ascendancy of the G.W. design in every particular admitted of no dispute. In 1927 this exchange was repeated by the loan of "Launceston Castle," of the same type as "Pendennis Castle," for a month of running between Euston and Carlisle, a 3-cylinder 4-4-0 Midland compound being transferred to Great Western metals for the same period. In view of the total disparity of size between the two machines, there was no intention of a direct comparison in this case, but the "Castle" was run on the L.M.S. trains in comparison with a 4-cylinder 4-6-0 "Claughton" engine, and once again the Swindon methods of design received full justification. Another interesting event of recent years was the journey of the Great Western 4-6-0 engine "King George V" to the Baltimore Exhibition in 1927, followed by some experimental running over the Baltimore and Ohio Railroad of the U.S.A , where the Swindon machine acquitted itself very creditably. As a memento of the exhibition, "King George V" brought back to England a typical American locomotive bell, which is now mounted (Plate 91) in the centre of the buffer-beam.

CHAPTER X

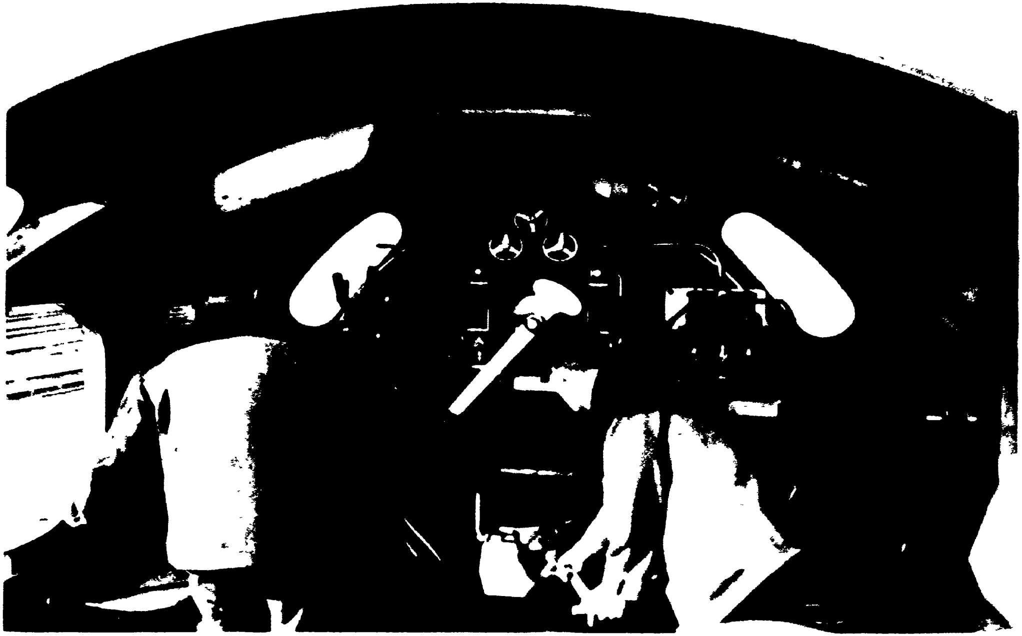
Electric Traction

THUS far, in our consideration of the motive power of the railway, we have confined ourselves to steam traction. It is correct that the steam locomotive should demand the major part of the attention devoted to the haulage of the trains, seeing that it still dominates railway traction to a vastly greater extent than all its rivals put together. Neither can it be doubted, for reasons which will presently be examined, that over the majority of railway routes the steam locomotive will continue to hold sway; such recent locomotive developments, in the direction of higher thermal efficiency, lower costs of maintenance and ability to remain in steam for longer periods together, as have been described in the three previous chapters, are in themselves a witness to the fact that the possibilities of the steam locomotive have not even yet been fully developed, and much less exhausted. Such rival forms of traction as the internal combustion engine have never got far beyond the experimental stage, and need no consideration at the moment. But electric railway traction—the most formidable of all the rivals to the steam locomotive—is in such widespread use as to require detailed examination.

It was not until late in the last century that electricity was first pressed into service for purposes of railway haulage. The first electrically-operated railway to be brought into use in the British Isles was the City and South London tube, opened for traffic in 1890 between the Bank and Stockwell.

The Liverpool Overhead Railway followed suit in 1893, being the first overhead electric railway in the world to come into use, just as the City and South London Railway had been the first tube railway in the world. Next came the Central London Railway—known at its opening as the "Twopenny Tube," as it established (but has since abandoned) the custom of charging a uniform fare of two-pence for any distance covered—which opened from the Bank to Shepherd's Bush in 1900. From that time forward electric traction has proceeded rapidly; not only has the whole network of the London tubes, exclusively worked by electricity, been completed and extended considerable distances into the surrounding country, but a substantial mileage of existing London suburban lines has been "electrified," or converted from steam to electric traction. The railway routes now worked electrically in England (there are none in Scotland or Ireland) add up to a total of 533 miles. In the Continent of Europe two-thirds of the railway mileage of Switzerland, including the whole of the important main lines, has now undergone electrification, and conversion of certain of the French main lines running through the hilly country of Central France is also proceeding apace. Considerable mileages of line have been electrified similarly in Italy, Austria and Sweden. In America electrification has been confined to lines conveying a heavy traffic in the neighbourhood of great cities, such as New York, Chicago, and Philadelphia, or to lines conveying a heavy mineral traffic, or to lines running through mountainous districts.

When we thus study the geographical location of the routes over which electric traction has replaced steam haulage, we are forced to the conclusion that there are certain clearly-defined conditions in which alone electrification can be expected to "pay." We notice, first of all, that



Pl. 80

Cab of "King Arthur" Class Locomotive, Southern Railway (p. 172)

The engine is fitted for left-hand drive, and the photograph shows the [illegible]

the suburban railway routes of great cities, with their dense and constant passenger traffic, are regarded as suitable subjects for electric working; the great majority of the electrified British railway mileage is of this character. We see, again, that a heavy and constant mineral traffic appears to justify electrification; a British conversion of this character from steam to electric working may be seen in the line connecting Shildon, in the colliery area of Durham, with Newport, near Middlesbrough, over which the L.N.E.R. brings heavy tonnages of coal and coke from the mines to the ironworks and steelworks of Cleveland and to the Middlesbrough Docks for shipment. Yet again, we find that railways in mountainous country, with the heavy gradients which invariably characterize mountain routes, are amongst the earliest to undergo electrification; the railways of Switzerland are a case in point.

These clearly-defined conditions governing electrification result from the fact that the provision of electrical equipment is enormously costly. It cannot, indeed, be contemplated unless there is a reasonable probability, either that reduction in working costs, or additional traffic attracted to the line by the expedited working that electrification renders possible, will pay interest on the capital cost of the conversion. Various other factors may bear on the question as to whether or not electrification will "pay." For example, in Switzerland the abundant sources of water-power, in the rushing streams carrying down to the valleys the melted snows from the mountains, are being harnessed to drive dynamos and thereby to produce the electricity required for railway working; here, therefore, the double advantage is enjoyed of a cheap source of power, on the one hand, and the ability to work heavy and continuous gradients in the most economical manner possible, on the other. An advantage of another kind is that electrification of a busy

line may render unnecessary the doubling of the tracks in order to carry the increasing traffic, as the more rapid acceleration of electric locomotives makes it practicable to put more trains on the line than before.

On lines that are carried through tunnels, again, an advantage of a minor but none the less important nature is that the vitiated and sulphurous atmosphere caused by hard-worked steam locomotives through the tunnels is done away with. In this connection it is striking to remember that the Elkhorn Tunnel, on the Norfolk and Western Railway of Virginia, U.S.A., provided one of the most emphatic of the reasons which finally compelled the electrification of that route. An increasing traffic in coal, made up into vast trainloads, was being worked over this route, and was greatly hampered by the foul air in this tunnel, which—despite the provision of powerful fans for ventilating the bore—so affected the train-crews that the management had to cut down to two the three Mallet locomotives charged with working each train up the 1 in 50 grade through the tunnel. The loss of this assistance just when it was most needed made it necessary to allow each coal train 20 minutes to traverse the 3,100 feet of the tunnel, and this was frequently exceeded. The substitution of electricity resulted in the Elkhorn tunnel being cleared in 3 instead of 20 minutes, and 6 electric locomotives are now doing as much work as was previously allotted to 20 immense compound articulated steam locomotives of the Mallet type. This was, of course, an extreme case, but the working of all routes which are largely tunnelled is greatly facilitated by electrification. Much of the attraction of travel amongst the Alps to-day, as compared with the old steam days, is due to the purer air and greatly increased cleanliness of the journeys, which allow of the uninterrupted enjoyment by the passenger of the panorama of scenery from the carriage

windows. As a still more extreme case, steam traction on one of the London tubes would be unthinkable.

The chief advantages of electrification are two in number. One, as already mentioned, is the great rapidity of acceleration from a dead start. It is this, rather than higher maximum speeds, that has the effect of so greatly expediting the working over suburban routes where electricity is substituted for steam. The power of the electric locomotive at low speeds (with the full resources of the power station from which to draw) is much greater than that of a steam locomotive of corresponding size and weight; further than this, motors can be distributed throughout each train—this is known as the "multiple-unit" system of working—although all under the control of one motorman. The power thus available makes possible very rapid starts from each of the frequent stops of a suburban route, and in the aggregate this rapid acceleration renders possible substantial cuts in the overall times of suburban journeys, so that the improvement of the service from the passenger's point of view is likely to attract traffic to the route. Further, the more rapid clearance of block signal sections makes it possible to crowd the trains more closely together, thus increasing the carrying capacity of the route, and this, as previously mentioned, may do away with the necessity of adding to the number of tracks, in order to accommodate an increasing traffic. The second great advantage is that the electric locomotive is always ready for use, and can remain in use for practically the whole of twenty-four hours continuously, apart from such brief time as may be needed for daily examination. No preparatory hours have to be spent in "lighting up" and raising steam, as in the case of the steam locomotive; no fuel cost is entailed when the engine is standing, as with the maintenance of the fire in a steam locomotive; the work of cleaning is halved; getting

the best out of the engine in the way of efficiency does not rest with the driver; and it is, also, feasible to work a train with a driving crew of one instead of two, which means a substantial cut in operating expenses. It is not open to question, again, that traffic can be worked in a far more systematic way with electric than with steam traction, for the reasons already given.

On the other hand, there are various formidable obstacles to electrification. Foremost amongst these is the cost. This is not confined alone to the electrical equipment. On many routes the substitution of electric for steam traction would not enable the railway company to put any further trains on the line, the capacity of which is limited by either its signalling, or the existence of "flat" junctions where trains cross each other's paths on the level, or similar hindrances. Costly rearrangement of tracks, the provision of automatic or power signalling, and other heavy expenses would thus have to be added to the cost of the electrification itself, if any adequate benefit were to be derived from the latter. It is this prospect which has for so long deterred the London and North Eastern Railway from attempting to electrify its London suburban area, where electrification would be of very great value, the huge cost entailed being unbalanced by any certain prospect of sufficiently reduced working expenses, or sufficiently increased traffic to pay interest on the capital sum which must necessarily be raised in advance. Then, again, the electrification of any extensive system or lengthy main line involves the displacement of large numbers of steam locomotives, for which it is difficult to find alternative duties, or, on the other hand, to sell at any reasonable proportion of their value. Some of the passenger rolling stock, moreover, is likely to be displaced as unsuitable for conversion into stock for electric working, in which rapid entrance and exit is a sine

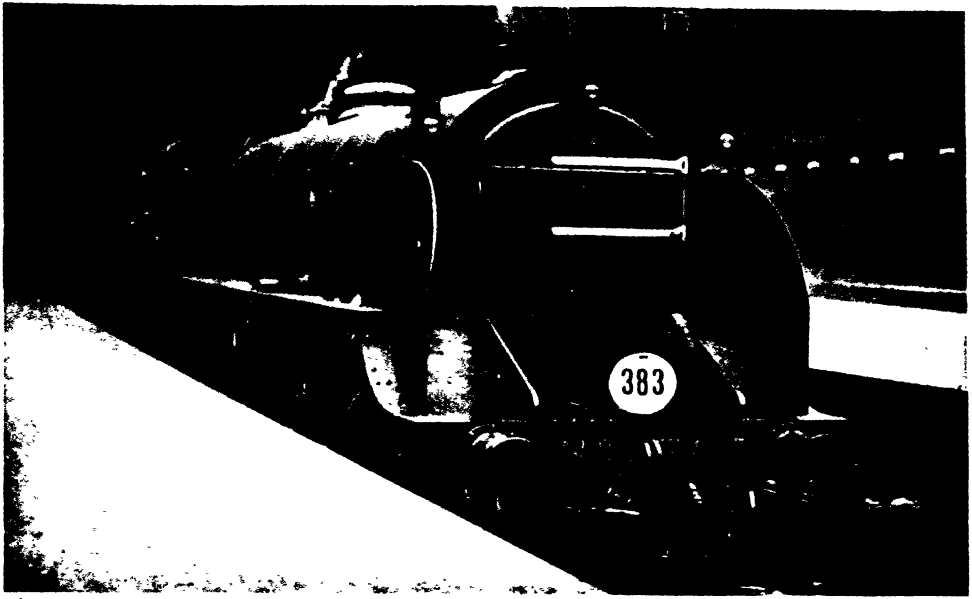
Photo by]

Pl. 91.

[N. 192

Great Western Express, Hauled by 4-6-0 Express Locomotive No. 6000 King George V p. 186

The engine bears on the buffer beam the bell presented by the Baltimore and Ohio Railway of the U.S.A.



F 92. O 193.

King Arthur class 4-6-0 Express Locomotive, Southern Railway (pp. 107, 176).

The deflector plates to left and right of the smokebox are designed to create an up current of air when [illegible] and so to lift the exhaust steam clear of the cab.

quâ non, if the full advantage of electrification on a suburban route is to be realized.

It is by centralizing at a power station all the power necessary to move the trains that a much higher efficiency is possible with electric than with steam working. The main power station is unhampered by restrictions of weight or of construction gauge ; thus the steam plant may consist of very large mechanically-fired water-tube boilers, high-speed turbines, and condensers which reduce the back-pressure to well below atmospheric pressure, and therefore greatly increase the proportion of the energy in the steam that can be turned into useful work. In itself the electrical plant is merely a power transmission system. The turbines are coupled to electrical generators which supply an alternating current at a high voltage ; this is transmitted by cables to various sub-stations, so situated as to redistribute the power to the actual track conductors at equally separated points. If the power were conducted directly from the main station to the railway transmission lines, a lower voltage would be essential in the case of direct-current systems, and desirable in that of alternating-current systems; for the same power the current would therefore be heavier, and the transmission losses, due to heating of the conductors, disproportionately greater. In direct-current systems the sub-stations convert the high-pressure alternating current to low-pressure direct current by means of large machines called "rotary convertors," which require skilled control and attendance ; in alternating-current systems the sub-stations may contain voltage transformers only, which function by virtue of the ratio of the number of turns of two coils wound round an iron core. These transformers may be very large, and require oil-cooling, but they need less attention, and the equipment of the sub-station in this case is smaller and simpler than in that of direct current.

To the output switches of the sub-station are connected the conductor rails or the overhead wire conductors, and the earthed running rails. Thus the conductor is always at "line voltage" whilst the power-station and sub-station are in operation, but no current will flow until the train starts to move in a section supplied by a sub-station, the wiring of the controllers and motors in the train completing the electric circuit. Any number of trains, of course, may be in a section at any time; they will then be taking power "in parallel," just as the electric lamps in a house take power in parallel off the electric light mains. The central station and sub-stations must be of sufficient capacity to meet the demands of the heaviest traffic on the line.

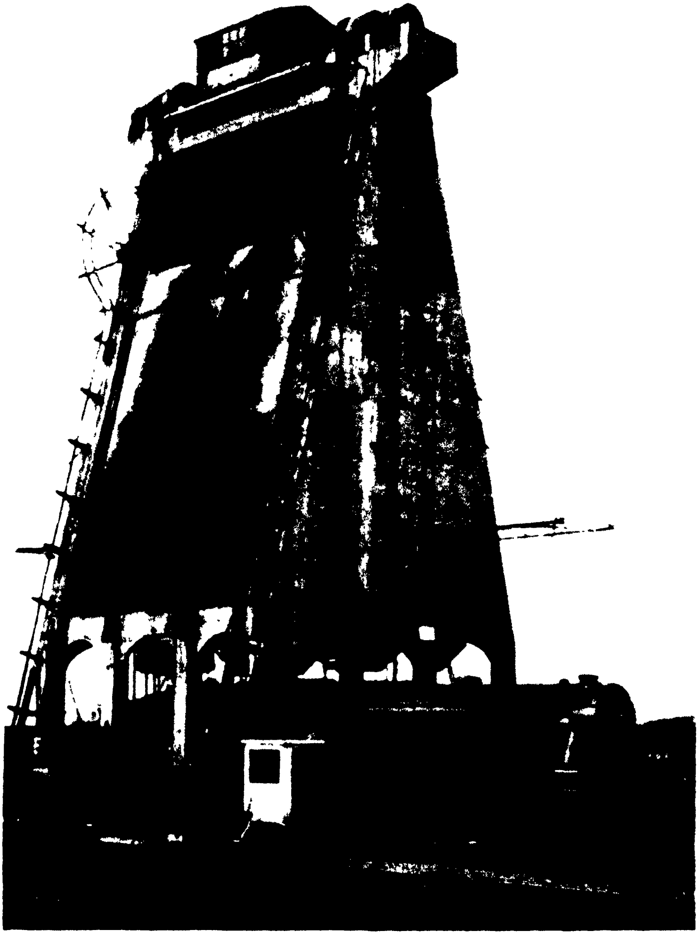
Of the many different types of electric motors, both for alternating and for direct current, only a certain number are suitable for railway use, as the type employed must be capable of exerting a large "torque," or turning moment, on starting, and must also be of the kind in which the speed automatically decreases as the current increases, so that the motors shall not overload themselves by rushing the trains up adverse gradients at full speed. Direct-current motors meet average railway traction conditions the most simply and efficiently. They are always arranged in pairs to give two main running speeds—half speed when they are connected by the controller in series, and full speed when in parallel. They are more compact than alternating-current equipments of the same power output; and in this connection it must not be forgotten that the limitations of space affecting the design of steam locomotives are no less severe in their effect on the design of electric locomotives. Further, direct current motors have the advantage of high efficiency and comparative cheapness.

Control of the motors in a multiple-unit suburban train—such as a six-coach train on the direct-current sections of

the Southern Railway—is effected by a most ingenious piece of apparatus. On one of these trains there are four pairs of motors, distributed throughout the train. Not only are they all controlled from one driving compartment by a "master-controller," but in addition the driver may move his handle to the first running position, and the motors will automatically accelerate themselves at a fixed rate. When the motors are started, each pair is in series, and thus each motor receives only half the line voltage. To prevent a dangerous rush of current on starting, resistances are also inserted in series with each motor at first; acceleration is then effected by cutting out these resistances step by step, then by reinserting the resistance and changing over each pair of motors from series to parallel, and lastly by cutting out the resistance by degrees until the full running position is reached. Only a small auxiliary current actually passes through the master-controller. This operates a series of "contactors" underneath the motor-coach, which make and break the current as each stage of acceleration is passed through. Generally the contactors are operated electrically, the control current energizing a magnet which moves a plunger, but in the Westinghouse electro-pneumatic system the control current is made to admit compressed air to each contactor in turn. With automatic control, acceleration is governed by a "limit switch," and the arrangement is such that when the motor current has dropped to a predetermined value, the next contactor is automatically operated. In this way the rate of acceleration of a train is definitely limited (though it is in the driver's power, of course, to *retard* it), and this automatic control is one of the factors which make an electrically-operated train service amenable to that exactitude of timing which alone could make possible the frequency and regularity which is characteristic of electric working.

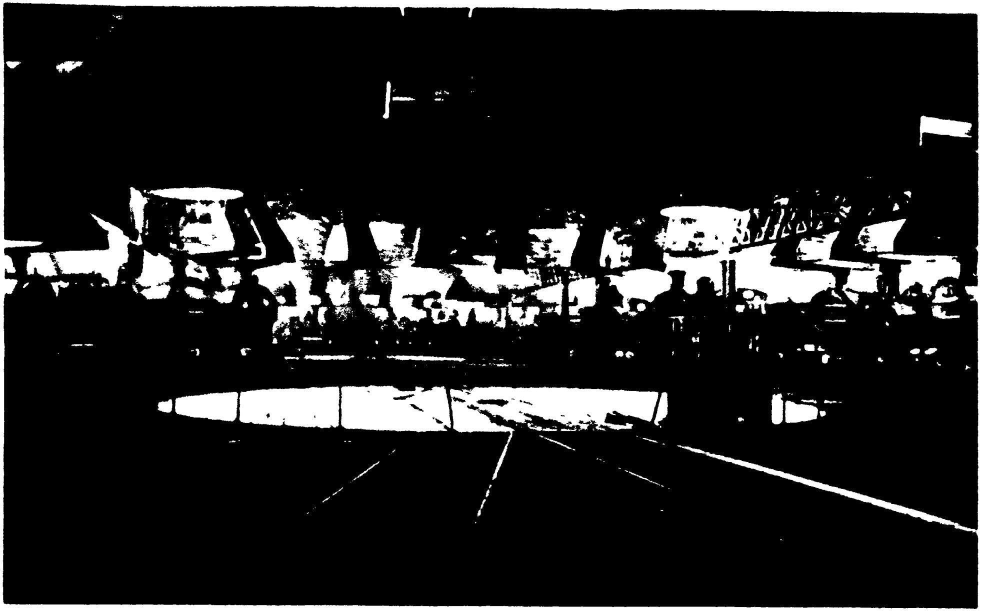
Multiple-unit train operation is practised on all the electric passenger services round London, the favourite method being to assemble the coaches in sets of three, the two outer coaches being motor-coaches (Plate 96), with driving compartments at the outermost ends, and the centre coach a "trailer." Such a formation as this is adequate for the needs of midday traffic, but for the "rush" hours of morning and evening a second unit of three coaches is added to the first (Plate 102), the driver now controlling the motors of four coaches from the one driving compartment. Further trailer coaches are inserted if required between the two three-coach units. In this elastic way the motor-power employed is proportioned to the load that is being hauled, which would not be the case if independent electric locomotives were employed.

Alternating-current motors are generally simpler to control than direct-current motors, because in all alternating-current equipments a transformer forms one of the main items. The use of a transformer makes possible the high line voltage common to railways so equipped, with a reduction in the cross-sectional area of the live wire used for transmission purposes; but the transformer makes the equipment of the motor-coach or locomotive heavier and more bulky. Control can be readily effected by gradually switching in successive sections of the secondary winding of the transformer, and thus varying the voltage applied. Contactors are generally used, but their arrangement and winding is simpler than in the case of direct-current equipment. The simplest of all alternating-current control systems is that employed in conjunction with the Déri brush-shifting motors, which are sometimes used on large electric locomotives, in which the voltage applied is varied by moving a set of adjustable "brushes" on the motor through various angles; the brushes con-



Mitchell Locomotive Coaling Plant, Doncaster, L.N.E.R. (p. 179.)

The coal wagon (seen on extreme left) is carried up the side of the tower by hydraulic lift, and tipped bodily so that the contents fall into the bunker, whence the coal is delivered to the engine tenders.



Round-House Type of Locomotive Shed, Derby (pp. 180, 182)

vey the current to the rotating armature by a sliding contact.

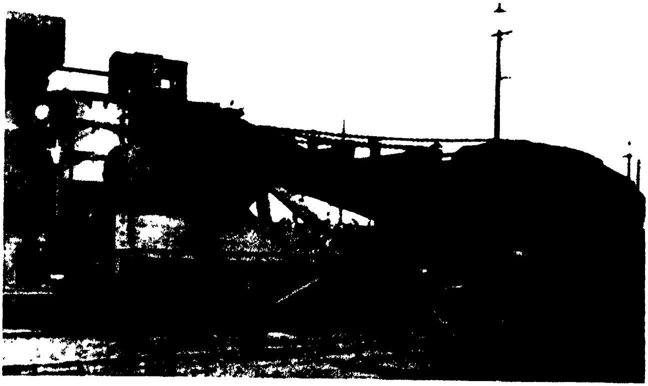
For train services of great frequency, for maximum reliability and for lower costs of maintenance when installed, there is little doubt that the advantage lies with direct-current electrification, in which the current is usually picked up from a third rail, laid either between or at the side of the running rails. This method is subdivided into those installations in which the current is returned to the power-stations by means of a fourth rail (Plates 96 and 140), as on the lines of the London Metropolitan and Metropolitan District Railways and certain of the tubes, or those in which the return is through the ordinary running rails. For the conductors a special "conductivity" steel is employed, which is the nearest approach to pure iron that it is possible to produce and to roll out. The objection to " third " and " fourth " rail electrification is that very complicated track-work is necessary through switches and crossings, with a number of breaks in the continuity of the conductors where the rails actually cross, and that, in countries with heavy winter snowfalls, it takes a comparatively moderate fall to cover the conductors altogether. Even on our British lines, the formation of ice on the conductor rails, after a winter fall of rain, sleet or snow, has sometimes resulted in the train service being brought temporarily to a standstill.

A voltage of 600 D.C. is used on practically all the electrified London lines, both on the surface and underground. With direct current of higher voltages than 600, overhead electrification is usually resorted to, and in these circumstances 1,500 volts is regarded as the most satisfactory figure for railway use; this has now been adopted as standard in a number of countries. Direct current voltages as high as 3,000 volts have their advantages in

the electrification of lengthy lines with infrequent trains, and have been successfully adopted in various American railway electrifications; but as higher direct-current voltages increase both the weight and cost of motors, as well as the complexity of control equipment, the lowest voltage practicable is generally employed, especially in the operation of frequent short-distance train services.

A large proportion of the world's railway electrification has been carried out, however, with alternating current, in conjunction with overhead electrification (Fig. 35); practically the whole of the Swiss, Swedish, Italian and South African railway projects are of this character. With alternating current far higher voltages are employed. The standard in Switzerland, for example, is 15,000 volts, at 16⅔ cycles per second. At the various main power-stations in Switzerland current is generated by water-power at either 132,000 or 66,000 volts, and is then carried by overhead transmissions to sub-stations, where it is transformed successively to 66,000 and then to 15,000 volts. The advantage of the single-phase system is that potential can be collected from one single overhead contact wire, and with such high voltages as these comparatively little copper is required in the distributing circuits, both of which conditions tend to cheapen initial costs. There are certain advantages in the three-phase system, but these are offset by the necessity for double overhead contact lines, which become extremely complicated at junctions and in station yards. Only in Italy has the three-phase system become popular, and all the Italian main line electrification is of this type.

For main line work the independent electric locomotive is essential, as the same stock, both passenger and freight, must, in the great majority of cases, be adaptable for working by either steam or electric engines, according to



P. 95 | 198.

Steam Breakdown Crane, Southern Rly.

O 100

Electric Tube Motor-Coach, Underground Electric Rlys. of London (pp. 196, 197)

whether it is passing over the non-electrified or electrified sections of the line. In this country, independent electric locomotives (Plates 97 and 100) are used by the Metropolitan Railway for working trains for the Aylesbury line as far as Rickmansworth, where a steam locomotive is substituted for the remainder of the journey. Again, independent locomotives have to be used for the working of the L.N.E.R. coal trains over the electrified route from Shildon to Middlesbrough. For working the main lines of Switzerland and France the independent electric engine is used exclusively. The most recent express engines of the Paris-Orléans Railway of France are fine machines of 107 tons' weight, capable of exerting a tractive effort of 18,650 lb. at 56 m.p.h., rated at 2,820 total horse-power, and have been timed at a maximum speed of 105 miles per hour. Plate 104 illustrates a considerably larger locomotive designed for mixed passenger and freight service, which is claimed to be the most powerful electric locomotive in the world. It has been built by the Italian firm of Ernesto Breda, of Milan, for service over the Lötschberg-Simplon Railway of Switzerland, to whose remarkable engineering attention has already been directed in Chapter 2. We saw there that the ruling grade of the Lötschberg line is 1 in 37, in long continuous stretches, and the contract for these engines called for a machine capable of hauling a train weighing 542 English tons up this gradient at a sustained speed of 50 kilometres (31½ miles) per hour. So handsomely was this requirement bettered that this locomotive *started* a 16-coach train weighing 600 tons, not only on the grade, but on the sharpest of the curves, at the end of one of the double loops near Blausee-Mitthölz, and with it attained a speed of 40 m.p.h. on the ascent. The locomotive weighs 138½ tons, of which 114½ tons are available for adhesion (the wheel notation is 2-6-0 + 0-6-2),

and is 66 ft. 6 in. in length; the six twin motors are capable of exerting a maximum of 4,500 horse-power for limited periods, and a continuous horse-power of 3,700. Many most ingenious devices characterise both the design of this powerful electric locomotive and the method of its control. In regard to weight, the electric locomotive has, of course, one advantage as compared with the steam locomotive, in that the latter incorporates both the source of power—the boiler—and the means of turning it into work, whereas the power of the electric locomotive is produced at the power-station, the locomotive in the latter case embodying the motor-gear (with the transformer in the case of A.C. equipment), and, moreover, not requiring to be saddled with the weight of a heavy tender carrying supplies of fuel and water.

The longest continuous stretch of main line ever yet electrified has been the 440 miles of the Chicago, Milwaukee and St. Paul Railway of the U.S.A., between Harlowton, Montana, and Avery, Idaho, on the main line from Chicago to Seattle. Here, apparently, was an ideal route for electrification. From Harlowton, at an altitude of 4,163 ft., the railway climbs to 5,788ft. in the Belt Mountains, and then drops to 4,066 ft. at Three Forks. Next follows the ascent of the main Continental "Divide," in the Rockies, which is crossed at Donald, 6,322 ft. above the sea. Last, after a fall to 2,680 ft. at St. Regis, the trains have to cross the Bitter Root range by Pipestone Tunnel, 4,163 ft. above the sea, before dropping to a level of 2,495 ft. at Avery, where the electrified section ends. These differences in level involve one 40-mile ascent at 1 in 100, a climb of 10½ miles at 1 in 60 and a 21-mile climb as steep as 1 in 50. The electricity is generated by water-power, as in Switzerland, and electric power is re-created by what is

known as "regenerative braking"; that is to say, on the falling gradients the motors are made to absorb the mechanical energy given to the trains by gravity, to translate it to electrical energy and to return this to the power stations, while at the same time efficiently braking their loads. Yet, even in such favourable conditions as these, the electrification of this 440-mile route nearly proved the ruin of the railway company which undertook it; a receivership was for a time inevitable, although now with improved traffic and prospects, it has been brought to an end. The explanation, no doubt, is that the amount of traffic passing over the route has not as yet been sufficient to meet, by the reduced cost of its operation, the interest on the capital cost of the electrical installation.

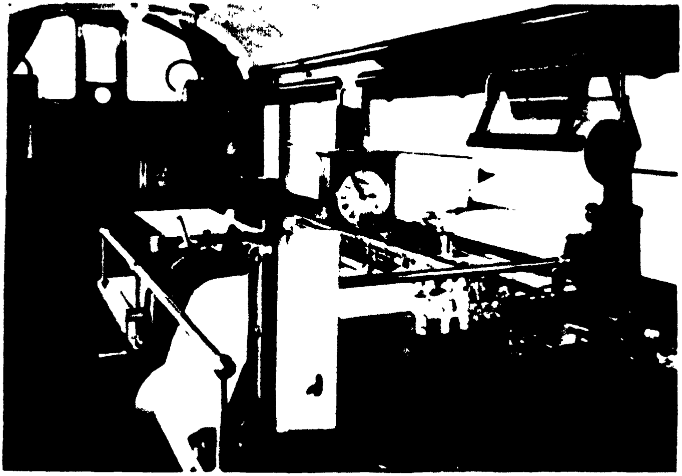
In Switzerland the progress of electrification was greatly hastened by the war; Switzerland has no coal of her own, and the supplies of imported coal, derived from Germany, slackened during the war period until finally they ceased altogether. The electrifying of the railways was therefore pressed forward with all speed, and the fact that all the material had to be purchased at a time when costs were at their highest saddled the Swiss railway administration with an even greater burden of capital cost in electrification than would otherwise have been the case. As a result, years elapsed before the main line electrifications of Switzerland could be regarded as a success economically; with post-war railway traffic at a level only 80 per cent. of the pre-war level, the working expenses, including interest on the expenditure involved, were up by 29 per cent., while the economies realized in working amounted only to 26 per cent. When at last the pre-war volume of traffic was regained, the two figures were 30 and 32 per cent. respectively, showing a small balance on the right side. With every further increase in the traffic the profit

resulting from electrification is likely to increase proportionately.

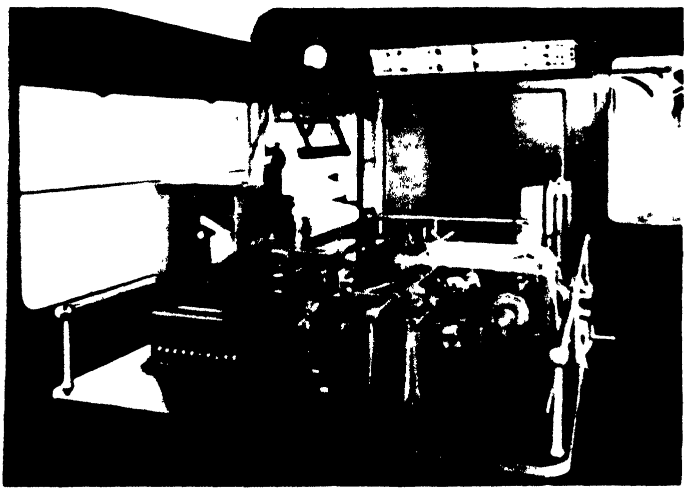
Some of the benefits conferred by electrification on the working of the Swiss railways have been remarkable. In general, the passenger express trains (Plate 103) have been speeded up from 20 to 25 per cent. in their journey times, and the stopping trains have been equally expedited. Up the continuous 1 in 37 to 1 in 40 gradients of the St. Gothard route the maximum steam locomotive load of 320 tons has been increased, with each electric locomotive, to 490 tons (Plate 106); the maximum load of coal (*en route* from Germany to Italy) taken over the route in one day has grown from 11,200 tons in 1915 to 21,800 tons in 1927. The cost of locomotive maintenance per mile covered has dropped from 5½d. per steam locomotive to 4½d. per electric locomotive; the latter is in actual working for an average—over the year—of 80 per cent. of each day, as compared with the steam locomotive's average of 40 per cent. It is expected that when the total mileage of electrified line in Switzerland has risen to a full one thousand miles, the electric locomotives required will only total one-half the previous stock of steam locomotives. And yet it is striking that in Switzerland, with every inducement to electrify—on the dual grounds of heavy gradients and cheap power resources—increased traffic has to be secured before justification is found for the expenditure involved. The total cost of Swiss railway electrification is estimated at roughly 28 millions sterling.

The most successful of the British railway electrification schemes has probably been that of the Southern Railway, which now owns the most extensive system of suburban electric railways in the world. The present mileage of Southern Railway routes electrified is 256 miles, but the single tracks now electrically equipped amount to no

Fig. 97. Electric Locomotive No. 18, "Michael Faraday," Metropolitan Rly. (p. [illegible])



Operating side of table, showing paper roll and recording pens



than 875 miles. It is somewhat unfortunate for the Southern management that the constituent companies of this group chose different methods of electrifying their lines. The London, Brighton and South Coast Railway, which took the lead in 1909 by electrifying the South London Line, chose the "overhead" system, with alternating current, but the London and South Western Railway, which followed suit in 1915, with its first electrified section, favoured a conductor rail, with direct current, instead of overhead transmission. Immediately before the grouping the first electrified sections of the South Eastern and Chatham Railway were opened, also on the "third rail" system. A considerable amount of money has been spent by the Southern Railway, therefore, in converting all the Central Division tracks and trains to the system obtaining on the other two sections of the railway. The expenditure on the Southern electrifications has more than justified itself, not only by reduced operating costs, but by the vast increase of suburban traffic which has been attracted to the system, some of it off the roads, but much of it by extensive building developments which have taken place round the electrified lines.

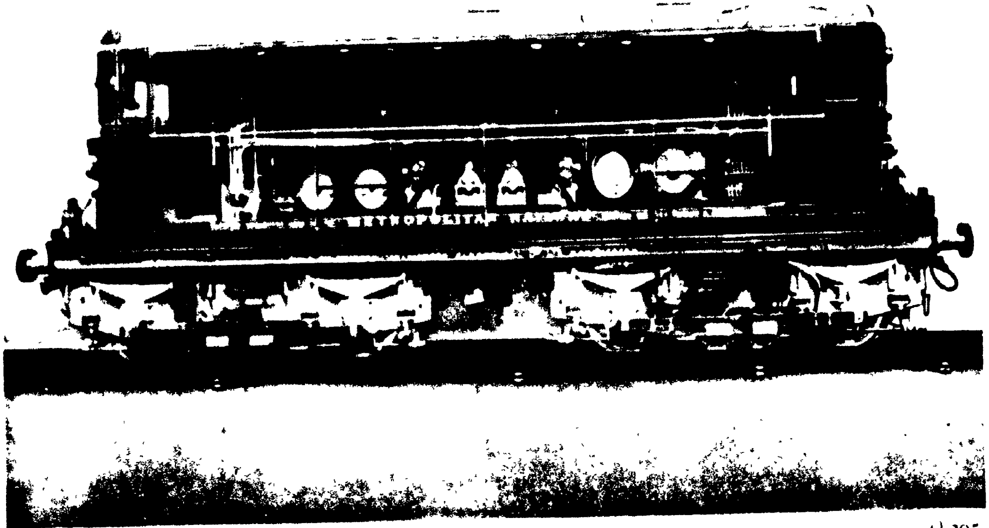
Other successful electrification schemes have been those of the late London and North Western Railway, from Euston and Broad Street out to Watford, and, further north, the Liverpool and Southport and Manchester and Bury lines of the late Lancashire and Yorkshire Railway; all these form part of the present L.M.S. system. Of the London and North Eastern Railway only the late North Eastern Company has tried electrification; the busy passenger lines between Newcastle and the coast, and the mineral line between Shildon and Middlesbrough (Plate 109), have been electrically-equipped, with successful results. Then, of course, there are the London Metropolitan and Metro-

politan District lines, once steam-worked, but converted to electric traction in 1905 and the years immediately following. Last of all there is the amazing network of the London tubes, which between them possess the most extensive system of underground lines to be found serving any city in the world. The methods of working electric train services, however, are considered in greater detail in Chapter XIV; here we are concerned more particularly with the motive power itself.

Extended reference has been made in the preceding chapters to the low overall thermal efficiency of the steam locomotive. In electrical working it may be assumed, from research on the subject, that the loss of electrical efficiency, between the generating station and the contact between wheels and rail, is roughly 40 per cent. Where the electricity is produced by steam, the overall thermal efficiency of a modern power-station may be taken at 20 per cent., in the best conditions. It is possible, therefore, for electrical railway working, when the electricity is produced from coal—as is practically essential in a country like our own—to show an overall efficiency of 12 per cent., as compared with steam locomotive's average, in continuous running, of 6 per cent. Such a comparison as this cannot lightly be dismissed. But for reasons which we have thoroughly examined in this chapter, the enormous cost of conversion from steam to electrical working, with the cost of associated improvements without which the electrification would have little value, is likely for some time to come to hamper the development of electric traction on railways.

Fig. 90. C 204

"King Arthur" Class Express Locomotive fitted with indicating shelter, Southern Railway (p. 180)



O 205.

Electric Locomotive (0-4-4-0 Type) Metropolitan Railway (p. 199)

The side has been removed to show electrical equipment

PART III

THE TRAINS

CHAPTER XI

Passenger Classes and Coaches

THE railway passenger, accustomed to expect, almost as a right, the luxurious accommodation afforded him in our express trains of to-day, seldom pauses to reflect, one imagines, on the various stages by which the primitive vehicles of years gone by have evolved into our palatial modern coaching stock. It would be impossible, in the space at our disposal, to trace the whole course of this evolution. In the earliest days the idea was to transfer to wheels and axles suited for running over the railway coach-bodies closely resembling those of the stage-coaches running over the roads. Such accommodation was provided for the first-class passengers only, and just as lower fares were charged for outside places on the coaches, so railway passengers by second class were required to ride in the most primitive of open trucks, provided with seating accommodation for the purpose. In a comparatively short time the increasing speed of trains and the discomfort caused to passengers by smoke and cinders from the engines compelled the introduction of covered coaches for the lower class of passengers; and the statutory provision of Parliament that at least one train per day should be provided over each route at a fare not exceeding one penny per mile led to the eventual introduction of a still lower, or "Parliamentary" class.

As passenger travel became better established, distinctions began to be made between train and train. The

"Parliamentary" passenger was confined to trains which called at all stations, generally not more than one or two daily over each route. The best trains, such as the "mails," conveyed only first class passengers, the privilege of travelling by them being then gradually extended to the second class passenger. After that came the bombshell—as it proved to be in railway circles—of the Midland and Great Eastern Railway announcements that from January 1st, 1872, third class passengers would be conveyed by all their trains. The Midland had barely four years before opened its London terminus at St. Pancras, and drastic measures were necessary in order to attract traffic to the new route. But all the other main lines of railway had, in course of time, to follow suit, and the inevitable result was a decline in the patronage given to second class; this decline has now resulted in the total disappearance of second class coaches from British trains, except in the case of the London suburban services of the London and North Eastern Railway, and the boat trains connecting with the services of Continental railways, where second class still obtains.

Whether or not three classes are necessary is always a vexed question; in fact, considerable argument is devoted to the question as to whether even two classes are necessary. On tube railways, where maximum accommodation is required in minimum space, and the journeys are short, there is certainly no justification for more than one class; the would-be first-class passenger over short distances has always the taxi at his command. But the case in regard to long-distance travel is on a different footing. It is that the railway is a "seller" of transportation, and that, if there are passengers desirous of purchasing a superior grade, and, what is more, prepared to pay for it, the railway is bound to meet their requirements. It is a moot point, indeed, whether even the abolition of second class in Great Britain

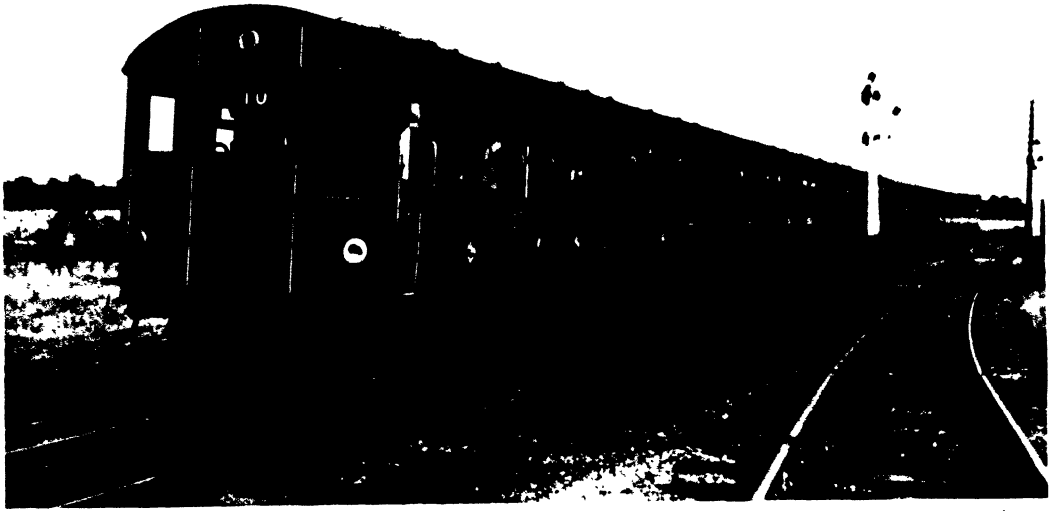
was not premature; the retention of the principle of carrying only first and second class passengers by the fastest and most luxurious trains would not only have perpetuated the reasonable idea of making the passenger pay somewhat in proportion to the quality of the transportation that he buys, but might even have made possible a lower rate per mile for third-class transport. Even in the air to-day, the slower planes over certain routes, starting from the air ports at times less convenient than those of the midday services, are regarded as "second-class," and lower fares are charged accordingly. In ocean travel, for decades past, it has been recognized that the fares charged shall be roughly in proportion to the luxury and speed of the liner concerned.

Great Britain is the only important country in the world in which no fare distinction is made between trains of varying luxury and varying speeds, with the exception of the supplementary charges by several limited Pullman trains. On the Continent of Europe the best trains are composed entirely of dining and sleeping cars, or nowadays of Pullman cars, and are known as "trains-de-luxe"; they are only available to the holders of first-class tickets (except certain all-Pullman trains of both first and second class), with a supplementary charge in proportion to the distance covered. The fastest ordinary trains are, for the most part, confined to the use of first and second class passengers, third-class passengers being admitted only when travelling over considerable distances. But it should be remembered, in this connection, that the normal second-class fares in Continental countries are roughly equal to British third-class fares, whereas the Continental third-class fares are considerably lower. In Germany there was till recently a fourth class, but this was very primitive in character, and confined to the slow short-distance trains. By a recent decision, however, the German railways have reduced their

passenger classes to two—a second, or "upholstered" class, and a third, or "wooden" class, on all but their best express trains. On German railways an additional, though modest, seat-charge is made for the use of corridor expresses, known as "D" trains, and for the faster express trains, classed as "F," further additional charges are levied in proportion to the distance covered by the traveller.

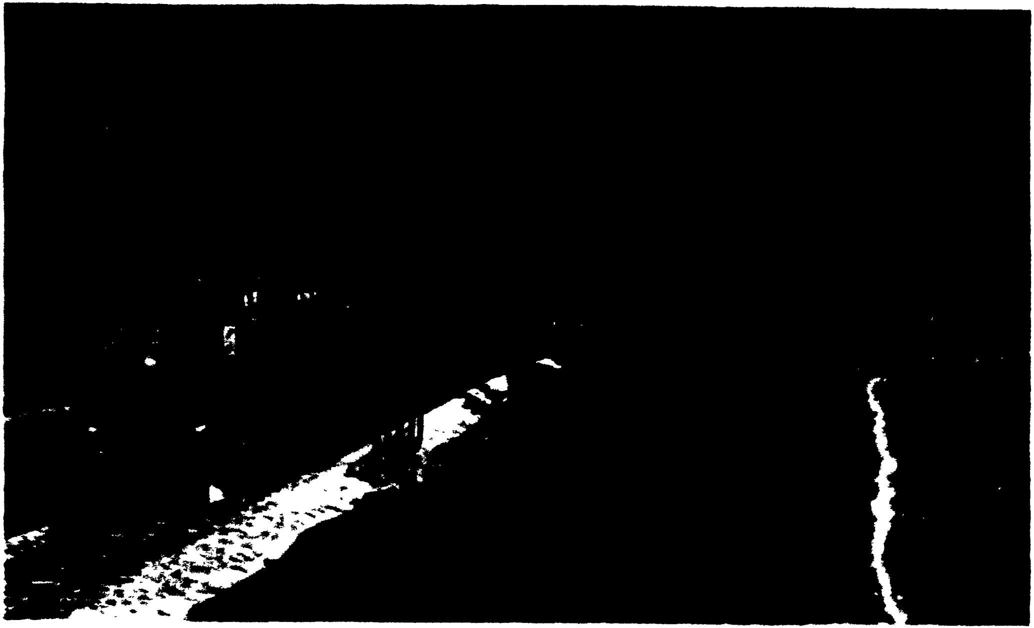
In America a different system prevails. There are no first, second or third classes, but the lowest grade of passenger travel is in what are known officially as "coaches." Superior comfort is obtainable in Pullman cars, which were the invention of an American named George Pullman, in 1867. In his desire to increase the comfort of railway travelling, Pullman devised the type of car which now bears his name, and proceeded, at a works which he established on the shore of Lake Erie, near Chicago, to build these cars in large numbers. They were then widely introduced on the American railways, Pullman paying a rental to the railways concerned for including his cars in their trains, and then recouping himself from the supplementary fares charged to passengers for the use of the Pullman accommodation. The Pullman car has now become a standard feature of American passenger services, and all the long-distance trains are composed chiefly of Pullmans. A Pullman supplement, varying with the distance covered, must be paid in addition to the "coaches" rate, and on the fastest expresses, such as the famous "Twentieth Century Limited," heavy additional supplements are exacted, on the basis of the hours economized by the traveller using them. In this connection it is interesting to note that, in the event of one of these "extra-fare" trains running late, the passenger is entitled to receive a refund of one dollar for every hour that the train is behind time.

Various types of Pullman are in use in America; the



Pl. 102. *P* 210

Multiple-Unit Electric Train, Metropolitan Rly. (pp. [illegible])



P 211.

Electrically-hauled Express, St. Gotthard Rly., Switzerland (p. 302).

Pullman parlour car (Plate 113), furnished with arm-chairs, is favoured for short distances, and the Pullman " sleeper " for longer journeys. The latter is provided with comfortable seating accommodation, which is converted at night into longitudinal sleeping berths, while additional berths are let down from inside the roofs of the cars, making two rows of berths, one above the other, on each side of the car, as shown in Plate 115. Curtains are then drawn down both sides of the car, for privacy, and the passengers must dress and undress in their berths. This is one respect in which American passenger accommodation is inferior to British, as the British sleeping car is provided with separate compartments for each passenger ; on the other hand, the use of the latter cars cannot be obtained unless the passenger pays first class fare, in addition to the sleeping car charge. It is interesting to note that in Canada and the United States, however, the compartment type of sleeper is beginning to come into use. British railways have just introduced sleeping accommodation for third-class passengers, on the longest night journeys, in compartment coaches (Plate 119) which have let-down berths above the ordinary seats, providing lying-down facilities for four passengers per compartment ; the arrangement of the cars for day and night use is shown in Plate 118.

It was in 1873 that the Midland Railway introduced the Pullman car to England. Pullman sleeping cars first worked between London and Glasgow, followed by Pullman drawing room cars between London, Bradford and Manchester. But on the Midland the cars never found great favour, and it was not until the late London, Brighton and South Coast Railway tried the drawing-room car type of vehicle on their short-journey expresses between London and Brighton, in 1877, that the Pullman idea began to make real headway. Since then the Pullman Car Company

that became established in Great Britain has made great strides. To-day every one of the Continental boat trains running from London on both the Southern and London and North Eastern Railways includes Pullman cars in its formation ; practically every express between London and the Kent and Sussex coast resorts is similarly equipped ; luxurious " All-Pullman " expresses are now running, such as the " Southern Belle " of the Southern, and the long-distance " Queen of Scots " and " West Riding Pullman " of the L.N.E.R. ; and in Scotland, on the Caledonian section of the L.M.S., as well as, more recently, in Ireland, the Pullman car has become very popular. Third class as well as first class Pullman cars are run in the majority of these trains, the credit for their introduction, in 1915, also belonging to the late L.B. & S C.R. A typical British Pullman car is shown in Plate 107, and its interior in Plate 116 No Pullman cars run over the L.M.S. lines in England, but this company has introduced large numbers of luxurious open vestibuled cars (Plates 116 and 110), one or more of which is included in the formation of practically every express, without extra charge, for the use of passengers who prefer this type of vehicle to the compartment coach. The latest first-class cars of this type, running in the " Royal Scot " express, are palatial vehicles, seated partly with movable arm-chairs, and the illustration given in Plate 108 shows the unusual note which has been struck in the internal fitting of these fine coaches.

During the last two years the Pullman car has made its appearance on the Continent of Europe. Here the Pullman coaches, as well as the whole of the dining and sleeping cars of the ordinary types, are under the control of a powerful company known as the " Compagnie Internationale des Wagons Lits et des Grands Express Européens," which may be seen inscribed at length above the windows of all

Photo.]

Pl. 104.

P. 212.

Electric Locomotive (2-6-8-2 Type) Lotschberg Rly., Switzerland (p. 100)

to take refreshments, and it was only by payment of an indemnity of £10,000 to the Swindon company that the G.W.R. was able to obtain release from the undertaking. But since the beginning of the present century, the progress of the restaurant car business in this country has been enormously rapid. Suffice it to say that in the summer of 1928 no less that 724 British trains ran daily on which it was possible for the passenger to obtain meals or refreshments, either in restaurant cars, Pullman cars, or, in the case of light refreshments, served out of small pantries located in ordinary coaches.

All these increases in the amenities of railway travel have added enormously to the cost of railway operation. We have here in large measure, indeed, the reason why such constant increases are necessary in express locomotive power, while the speeds of the trains themselves have remained more or less stationary for several decades. The seating capacity of a corridor third class compartment is at most four aside, whereas the corresponding non-corridor compartment can take five with comfort, and even six without great difficulty. Further space is taken up by lavatories, which might otherwise be used as compartments. In restaurant cars, from the passenger-carrying point of view, all that part of the car devoted to the service of the meals—kitchen, pantry and attendants' compartment—is but dead-weight, and the common practice of excluding passengers from the cars, except at mealtimes, means that the only revenue earned by these cars is that derived from the service of meals The result is that there is an almost continuous increase in the weight of rolling stock hauled, in proportion to the number of passengers that it accommodates, and each successive increase in passenger comfort tends to add yet further to the weight of train per passenger conveyed.

Pl. 106 | T 214

Electrically-hauled Freight Train at Airolo, St. Gotthard Rly., Switzerland (p. 312)

P 215.

First-Class Pullman Car "Phyllis," "Queen of Scots" Express, L.N.E.R. (p. 212).

No more striking illustration of this could be given, probably, than the summer formation of the "Royal Scot" express of the L.M.S. (Plate 68). This consists of fourteen eight-wheeled vehicles, in the following order:—Combined brake coach and first-class lounge car (Plate 108), combined first-class coach and open first-class restaurant car (Plate 116), kitchen car, open third class restaurant car, three third class coaches (one open and two compartment type), and large luggage brake for Glasgow; with first class lounge car, first class and restaurant car, kitchen car, open third class restaurant car, third class coach and third class brake coach for Edinburgh. That is to say, out of 14 coaches, weighing empty 390 tons, 5 coaches, weighing 142 tons, are devoted entirely to the service of meals, and earn no passenger revenue. Two coaches and a half are given up to passengers' luggage. This leaves but 6½ coaches out of 14 that provide passenger seating; even if every seat were occupied, the total seating accommodation of this 390-ton train is but 298 third-class and 44 first-class seats, total 342 passengers. The empty weight of stock per passenger conveyed is therefore at the very least 1·14-ton. In comfortable non-corridor stock of modern design the same number of passengers and the same volume of luggage could be accommodated in seven coaches—reckoning only five passengers aside in the third-class and four aside in the first-class compartments—weighing 194 tons; this would give a figure of 0·49-ton per passenger conveyed. In this case, therefore, the provision of corridors, lavatories and ample restaurant-car facilities adds well over 100 per cent. to the total weight of rolling stock required.

It is always a debatable point whether passengers should be allowed to make their journeys in the restaurant cars. On the Great Western Railway—as on the railways of the

Continent and America (Plate 120)—the restaurant car is a travelling restaurant, purely and simply, and the general practice is to exclude passengers from it, except at meal-times. The Great Western, too, favours one open car for passengers of both classes, often seated with ordinary chairs, in order to afford the maximum possible accommodation. Open cars of this type, 70 ft. long, seating 56 diners, weigh about 37 tons, and not only reduce to a minimum the weight of the train devoted to the service of meals, but can be operated by a comparatively small staff. On other lines, however, the practice is more to increase the amount of seating accommodation, and to allow a limited number of passengers to travel throughout in the restaurant cars, provided they are agreeable, if necessary, to the vacation of their seats temporarily while other passengers take their meals. A pronounced tendency of the present time, especially on the L.M.S. line, is to reserve one coach entirely for the kitchen, pantry and attendants' compartment, which greatly increases the amount of space at the disposal of the staff. The alternative is to compress these offices into one end or the centre of the car, as in Great Western, Southern, Continental and American practice, or to run the restaurant cars in pairs, either with the kitchen in the end of one and the pantry in the adjacent end of the other, or both in the one car (generally the first class), which is then flanked with a large open car to give adequate space for the service of the third-class meals (Plate 105).

The British sleeping car is an even more weighty vehicle in proportion to its passenger accommodation. Every passenger is provided with a room to himself (Plate 117), containing, in the latest cars, an actual bed, together with a private lavatory with hot and cold running water, and every possible device to make for comfort, silence and smoothness of running. An average 12-wheeled sleeping car of the

L.M.S. Company weighs 44 tons, and accommodates 11 passengers, or 4 tons of coach weight per passenger conveyed, and it is not surprising, in the circumstances, that first class fare, with a supplement of 20s. per berth, should be charged. As has been mentioned previously, sleeping accommodation is now provided for third-class passengers on certain night trains in Great Britain, at an additional charge of 7s. per berth, in compartments fitted with four "lying-down" berths each, and provided with pillows and rugs.

We must now devote a little space to the various types of coaches in use. The earliest coaches were carried on four wheels, later increased to six wheels as the desirability of the lengthening of coaches, to provide increased accommodation, became apparent. It is difficult to determine exactly when the principle of bogie suspension of coaching stock was first devised, but for all descriptions of passenger rolling stock the bogie is now in practically universal use. Each end of each coach is thus supported on a kind of wheeled truck, which, exactly like that carrying the leading end of a locomotive, is free to swing about the pivot which transmits the coach weight to the truck frame. Bogie coaches are thus able to take the curves in the line smoothly and easily, and in addition the bogies themselves absorb a large proportion of the shocks which the coach would otherwise receive from the passage of switches and crossings, the joints in the rails and other slight inequalities in the track, producing that smooth and steady movement which is such a feature of present-day railway travel.

In order to reduce the weight of the bogie itself to a minimum, it is customary in this country to employ a bogie carried on four wheels, the two bogies giving a total of eight wheels supporting the coach (Plate 112). The six-wheeled bogie, making a twelve-wheeled vehicle, had in the past a somewhat extensive vogue in this country for coaches of

exceptional length, such as dining and sleeping cars, but practically the only 12-wheeled coaches now built for British use are the latest type of L.M.S. sleeping cars. On the Great Western Railway the standard length of coach for long-distance use is 70 ft., but these large vehicles (Plate 125) are invariably carried on eight wheels. Continental railways employ coaches up to 77 ft. long—such as the sleeping cars of the "Blue Train," or the Pullman cars of the "Golden Arrow"—and weighing up to 54 tons apiece, but supported on four-wheeled bogies. In America, on the other hand, the six-wheeled bogie (Plate 110) is the more usually employed, but the even greater length of American coaches, and their solid all-steel construction, makes them enormously weighty, 70-ton and 80-ton Pullman cars being by no means uncommon, as compared with a maximum of 45 tons for a twelve-wheeled coach in this country.

This question of the weight of coaching stock is of considerable importance. Not only has increased comfort occasioned great increases, as we have seen, in the weight of coaching stock per passenger conveyed, but more solid methods of construction, including the substitution of steel for wood wherever possible, in order to lengthen life and reduce costs of maintenance, also contribute to increased weight. Eight-wheeled corridor main line coaches on the London and North Eastern Railway, once weighing 28 or 29 tons each, have now increased to 34½ tons apiece; Great Western 70-ft. corridor cars, weighing from 31 to 33 tons when first built, are now mostly 35 and 36 tons in weight; and this increase has not been accompanied by any increase in seating accommodation. The L.M.S. Company alone appears to be grappling seriously with this problem, the weight of its standard corridor vehicles having dropped from an average of 30 tons per coach, in the case of L.& N.W. vehicles, to 28 or 27 tons. Thus, whereas the present-day

P. 108 P. 218.

First-Class Lounge Car. "Royal Scot" Express, L.M.S. Railway (p. 212, 21-).

P 219.

Overhead Electrification on the London & North Eastern Rly. (p. 203)

L.N.E. or G.W. express of, say, 12 coaches, weighs from 50 to 60 tons more than it did only ten years or so ago—an increase roughly equal to the addition of two coaches—the L.M.S. express of corresponding formation has dropped in weight by some 30 tons. The importance of these figures lies in the fact that every additional ton of train-weight calls for a proportionate, even if minute, increase in locomotive effort, which, in its turn, requires increased coal consumption.

An attempt has been made to reduce coach weight by the principle of "articulation," devised and introduced by Mr. H. N. Gresley, then Locomotive, Carriage and Wagon Superintendent of the Great Northern Railway, in 1906. The original idea was to make some old East Coast six-wheeled corridor coaches suitable for modern use by converting them to bogie stock; this was done by dismounting them from their wheels, and coupling them together permanently in pairs, with one central bogie supporting the two adjacent coach-ends (held together by a built-up steel cradle), and two bogies of the ordinary type at the outer ends. So this vehicle, some 80 ft. long but flexible about the centre, was made to give as steady riding as ordinary bogie stock.

Experience having amply proved the success of the principle of articulation, it was realized that it might be applied to a reduction in the weight and length of rolling stock. Since then a great deal of new articulated stock has been built, including twin sleeping cars, and the sets of restaurant cars used on the Scottish services. Each of the latter is a "triplet," consisting of a kitchen car in the centre, flanked by open first-class and third-class cars, and affording 36 first-class and 42 third-class seats; the weight of each "triplet" is 83 tons, as compared with the 98 tons of the set of three independent cars, of roughly the same

seating accommodation, previously in use. The latest of these sets, built specially for use on the " Flying Scotsman," incorporates some novel features, including a first-class dining saloon (Plate 1), which is an excellent reproduction of two rooms in the Louis XVI style. For the London and Leeds service a complete train of five vehicles—a " quintuple " set—has been built, similar to the sets just mentioned, but with the addition of first-class and third-class brake coaches at the two ends ; this weighs 120 tons. A number of older main line vehicles have been assembled into articulated sets on the L.N.E.R.—" twins," " triplets," " quadruplets " and " quintuplets "—making handy assembled units for branch line working. The only disadvantage of articulation is that in the event of a defect—such as a cracked tyre, a hot axle-box or any other minor defect—the whole of this indivisible assemblage of coaches must be withdrawn from service. It is possibly this consideration which has prevented the spread of the principle, the Great Western Railway being the only other British line which has built any articulated vehicles.

The method of coupling coaches together now requires consideration. Seeing that the tractive effort of the Great Western express engines of the " King " type is as high as 40,300 lb., it naturally follows that a maximum pull as high as 15 tons or more may be exerted on the couplings at the leading end of any exceptionally heavy express drawn by one of these engines. In the early days of railways, iron chains formed the connection between coach and coach, and the starting of a passenger train was as jerky a business as that of a loose-coupled freight train is to-day. In later years there came in the screw coupling, which in both England and Europe is the method still most generally employed. Screw couplings enable the distance between coaches to be nicely adjusted so that the coach

P. 110. Open Vestibuled Third Class Coach. L.M.S. Rly. p. 12 P 220

Facing p. 221

PL. III.

One Section of the "Twentieth Century Limited" at Full Speed (pp. 100, 248)

buffers are just in contact, and each coach is thus steadied by those immediately in front of and behind it. For many years it was customary in this country to supplement the screw couplings with side chains, as a precautionary measure, but the latter have now been abandoned.

From the beginning of the present century the American "buck-eye" principle of coupling has replaced the screw coupling on the East Coast expresses, and this method has now become standard for main line corridor stock on the London and North Eastern Railway (Plate 112). The ends of the coaches are bulged outwards, and the coupler is located on the centre-line of each coach, forming what is, in effect, a buffer and coupling combined. When two coaches are pushed together, the couplings engage automatically, after the manner of two hands making a handclasp, and the effect is to lock the whole of the carriage underframes together throughout the length of the train, in one strong and rigid, though perfectly flexible, steel frame. The strength of this system of coupling has been demonstrated in more than one derailment, which might have proved disastrous had not the whole of the coaches so coupled remained "in line," and thus been preserved from telescoping. When the buck-eye couplers are in use, the side buffers are dispensed with, and are constructed for that purpose with hinges, in order that they may be dropped out of position when required. A number of main line corridor vehicles of similar design (Plate 125) have also been constructed of recent years by the Great Western Railway.

The other vital connection between coaches is that of the brake-pipe. This is made from coach to coach by means of an armoured rubber hose-pipe, which affords a continuous communication from the engine to the last carriage, and enables the driver to apply the brakes on every pair of wheels throughout the train. Owing to the two dissimilar

methods of braking already referred to—the Westinghouse, or compressed air brake, on the one hand, and the automatic vacuum brake, on the other—a large proportion of the vehicles used on main lines has to be "dual fitted" or provided with both systems. There is now no direct "alarm" communication between coaches and locomotive, as obtained in the day of the "communication cord," which, when pulled, gave an audible signal on the engine by means of a bell. To-day the communication chain, located inside each compartment, has a direct action on the brakes. When it is pulled, the brakes are applied and a shrill whistle is blown on the coach concerned; the driver, hearing the latter and noting the movement of the needle on his brake-gauge, is apprised of the emergency, but is able to draw up his train at some place which will be attended with the least risk to passengers—that is, at the next station or signal-box, rather than in a tunnel or on a viaduct. When the train has been stopped, the coach in which the chain has been pulled is easily located by the fact of a protruding red indicator, working in conjunction with the chain. This method of passenger communication has proved far more reliable than the old communication cord.

Brief reference is necessary, in conclusion, to passenger carriage lighting and heating. For many years smoky oil lamps were employed for this purpose, but gave way ultimately to oil-gas, stored in cylinders under each coach. Then came the first days of electricity, which increased in favour until the day when an incandescent gas mantle was devised strong enough to stand the vibration of railway travel. After this incandescent gas lighting had a wide vogue, but one or two railway accidents in which disastrous fires followed the bursting of gas cylinders has, by Ministry of Transport order, caused a general reversion to electric lighting, which is now in practically universal use. Elec-

Pl. 112. P 222

All-steel Open Vestibuled Third Class Coach, L.N.E.R. (p. 221)

Showing jaw of automatic coupler, steam heat (left) and vacuum break (right) connections, gangway connection, and small plate on coach end (to left of vestibule) giving dimensions, accommodation and tare weight of coach.

P. 113 P. 223.

Pullman Parlor Car, Canadian National Rlys. (pp. 211, 249)

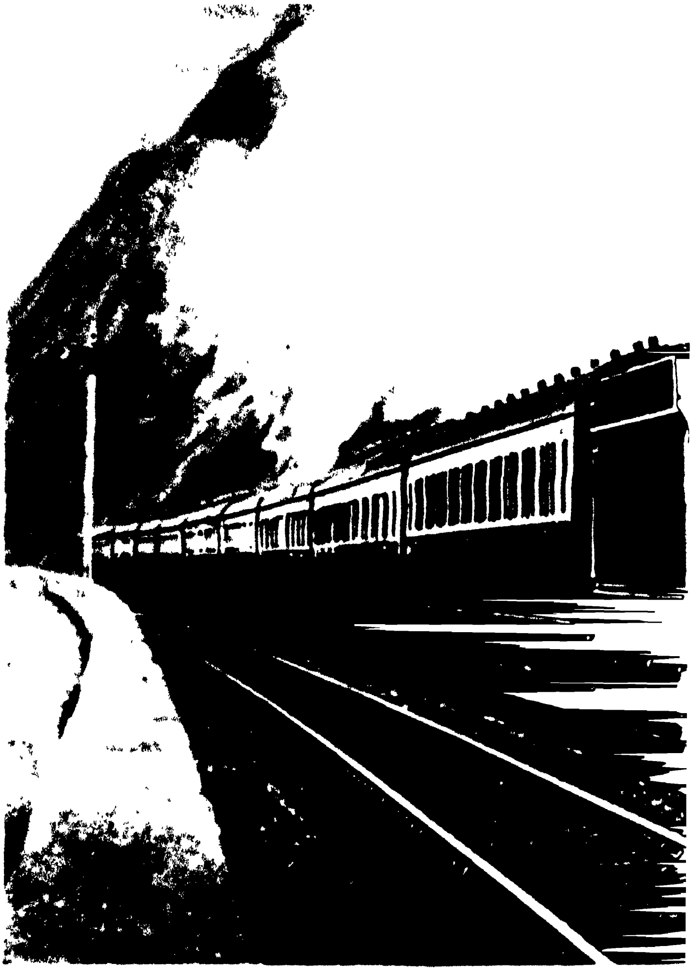
... the receiving set ... in right background, and head phones are hanging

tricity is generated by a dynamo driven off one of the axles of the coach concerned, and is then stored in capacious accumulators under the coach, so that there may be an ample supply of current even when the coach is standing. In the latest articulated restaurant car sets of the London and North Eastern Railway, to which reference has just been made, electricity so generated is pressed into service for cooking, in place of gas, with very successful results. So the constant "gassing" of restaurant cars at intermediate stations is done away with, the cooking on the cars is improved, and the lower temperature of the kitchens affords much improved comfort to the staff.

Until well into the present century, the only heat available in passenger compartments in the winter-time was that supplied by "foot-warmers"—flat steel containers, filled with hot water at various depots up and down the main lines, and laid on the floors of the compartments. Such antiquated methods have now been entirely abandoned in favour of "steam" heat; steam is supplied from the locomotive boiler, at a suitably reduced pressure, throughout the length of each train, connection from coach to coach being made by flexible hose-pipes. The heaters, communicating with the main steam-pipe, are located under the carriage seats, and the amount of steam admitted, regulating the degree of heat, is under the passengers' control. The steam supply is also used to heat the water in the lavatories for washing purposes in the winter months. Both heat and light in passenger trains thus add their quota to the work to be performed by the locomotives of passenger trains, the former by way of a drain on the steam supply, and the latter as a result of the increased frictional resistance occasioned by the driving of the dynamos.

Carriage-cleaning is an item of no small magnitude in railway expenditure. Much use is made of vacuum-

cleaning plants for cleaning the insides of the compartment: but the application of mechanical cleaning to the exterior c coaches is only of recent date. In Plate 121 is seen the lates carriage-washing plant in use at the Ealing Commo car-sheds of the Underground Railways of London; i this apparatus, of French design, the vertical rollers o both sides of the track, to which bundles or "mops" c rags, consisting of thousands of strips of cloth, each abou 2 ft. long, are attached, are made to rotate rapidly whil the coaches are passed between them, sprays of water bein directed against the coach-sides at the same time. Th apparatus has proved most effective in use, the exteri of a bogie coach being cleaned far more thoroughly in 1 minutes than it could be by hand in 10 minutes. Simil plants have since been brought into use on the L.N.E.I at York and elsewhere.



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CHAPTER XII

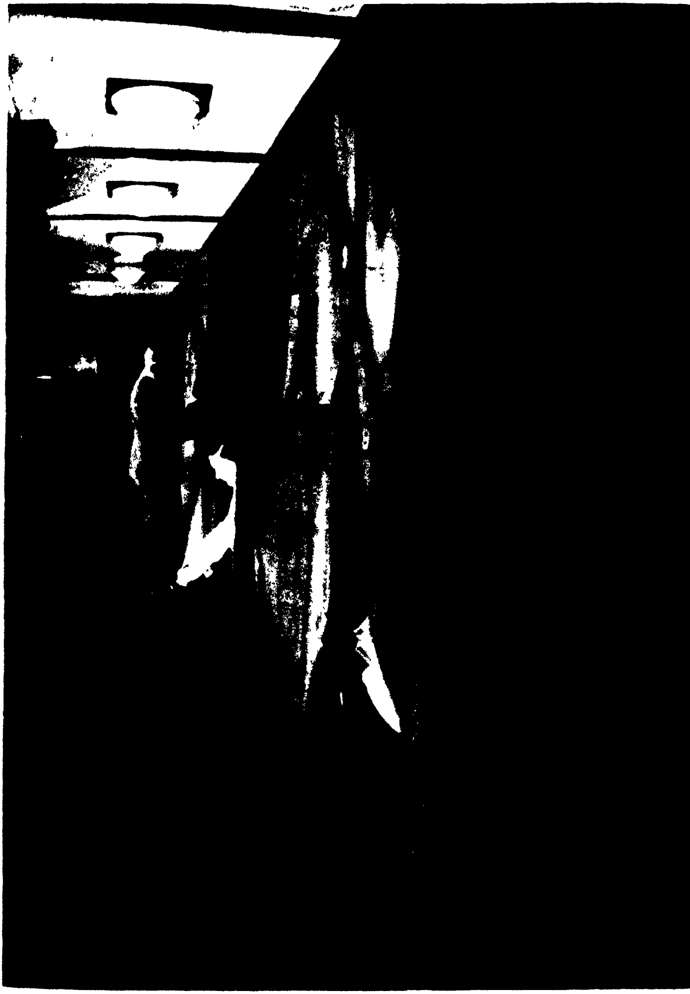
Express Passenger Services

It is hardly open to dispute that more glamour attaches in the public mind to the working of express passenger trains than to any other individual feature of railway operation. The fascination, indeed, is one that increases rather than decreases with the passage of time, and this is the more remarkable, perhaps, in view of the constantly increasing competition with the travel achievements of the railway of those by air, by road and by sea. One seldom opens a daily newspaper nowadays without discovering some reference to the latest speed performance on such-and-such an express, and the four railway groups appear to vie with one another in their keenness to secure honourable mention of this character in the Press.

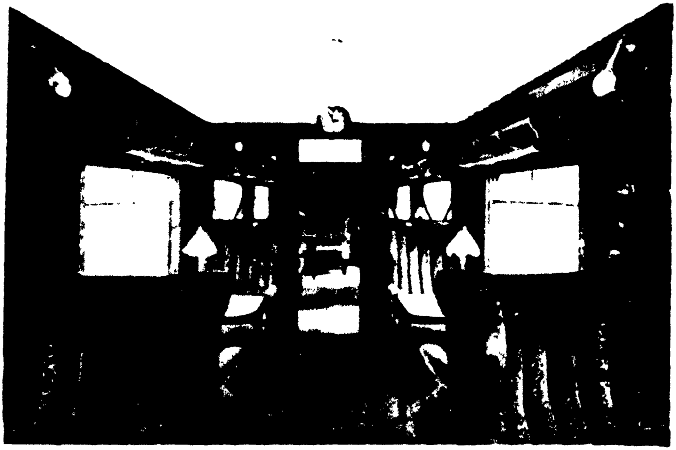
A measure of enhanced public interest in British express trains, too, is afforded by the recent outbreak of " naming " trains. Various historic train titles have endured through decades of railway history, such as the " Flying Scotsman " of the L.N.E.R. and the " Irish Mail " of the L.M.S., while the " Cornish Riviera Limited " of the Great Western and the " Southern Belle " of the Southern have been in existence for twenty years ; some names, on the other hand —like the " Flying Dutchman " of the G.W.R.—have disappeared because the trains concerned have vanished from the time-tables, in consequence of alterations to times and routes. Of more recent date are such titles as the " Atlantic Coast Express," the " Aberdonian," the " High-

landman," the "City Limited" and others; and the latest addition has been a flood of named L.M.S. expresses, headed by the "Royal Scot," and including the "Manxman," the "Welshman," the "Ulster Express," the "Lakes Express," the "Midday Scot," the "Night Scot," the "Yorkshireman," the "Devonian," and the "Pines Express."

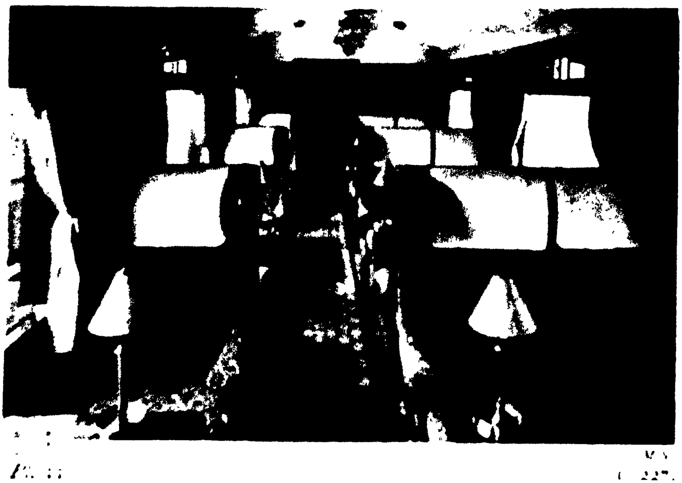
Such titles, designed in the first instance to attract public notice to the trains concerned, have a greater value, however, than the merely sentimental. In America, where the naming of trains first had a really extensive vogue, and where practically every express of to-day has its own distinctive title, the names are used for purposes of identification; they run into hundreds, many of them vividly descriptive, such as the "Twentieth Century Limited," the "Sunset Limited," the "Capitol Limited," the "Katy Flyer," the "Empire State Express," the "Congressional," and others far too numerous to mention. Such names are easier to remember than the times of the trains concerned, and especially so in the case of those of the expresses whose journeys extend over several days. The title "Limited," which is in such common use in America, and which is occasionally used in this country (as witness the "Cornish Riviera Limited" and the "Torbay Limited" expresses of the G.W.R.) is really intended to indicate that the number of seats on the train is limited to a certain maximum, and that these seats must be booked in advance; if all the places are filled, it is possible that last-minute passengers may not be carried. In practice, however, this limitation is seldom enforced. It is customary, for example, for the famous "Twentieth Century Limited" of the New York Central Lines, from New York to Chicago, to run in at least three parts, and very often in four or five, so that of limitation of carrying capacity there is really none. Another



Typical American Sleeping Car



First Class Pullman Car "Queen of Scots" Express, L.N.E.R.



limitation affecting the title employed is that, at certain of the intermediate stops made by "limited" trains, local passengers are not taken up or set down; that is, that the use of these trains is limited to long-distance travellers.

The most important of all factors in connection with the working of express trains is, of course, that of speed. It is, in fact, becoming of increasing importance in view of the growing speed and comfort of road transport and the far faster transport of the air. The day is probably not far distant when expedition of British express train services will become an imperative necessity, if this competition is to be met effectively. With certain notable excepttions, there has been but little quickening of British express trains for a quarter of a century past, even though, as was explained in the last chapter, the loads hauled by the locomotives have vastly increased during this period. The war, with the drastic deceleration of expresses that it rendered necessary, and the long period that had to ensue before recovery to pre-war times became possible, is responsible in part for this stagnation, but there is no doubt that, with the powerful and efficient express engines running to-day over the lines of each of the great groups, substantial cuts could be made in the travelling times between many of our great cities. Continental railways are waking up to the menace of aerial competition, and in France, Germany and Italy great strides are being made in the acceleration of express train services, with the result that France, in particular, is tending to displace Great Britain as the home of the fastest railway running in Europe.

The highest standard of British railway speed is, without any question, set by the Great Western Railway, which also holds most of the speed records in this country. Of the latter the most remarkable was made on May 9th,

1904, when the Great Western Company was racing the London and South Western with the mails and passengers off Transatlantic steamers which had called at Plymouth. London was the objective, the former line bringing up the mails and the latter the passengers. On the occasion in question, the journey of 246½ miles from Millbay Crossing at Plymouth to London (*via* Bristol, as this was prior to the opening of the Westbury route) was covered in 226¾ minutes, inclusive of a stop of 3¾ minutes at Pylle Hill Junction, Bristol, to detach the mails for the North of England. In the first stage of the run the 4–4–0 locomotive "City of Truro" attained the phenomenal speed of 102·3 miles per hour in the descent of Wellington bank, just before Taunton, and after leaving Bristol the 4–2–2 engine "Duke of Connaught" maintained an *average* speed of exactly 80 miles an hour all the way from mile-post 74½ to passing Westbourne Park, a distance of 73 miles which is almost perfectly level throughout. This was one of the most remarkable feats of railway speed that the world has ever seen, and was fully authenticated by the presence on the train of a recorder—the late Mr. Charles Rous-Marten—of many years' experience in train-timing. Various earlier speed records are claimed, especially for the Great Western broad gauge, but they have mostly been proved since to be either greatly exaggerated or purely apochryphal.

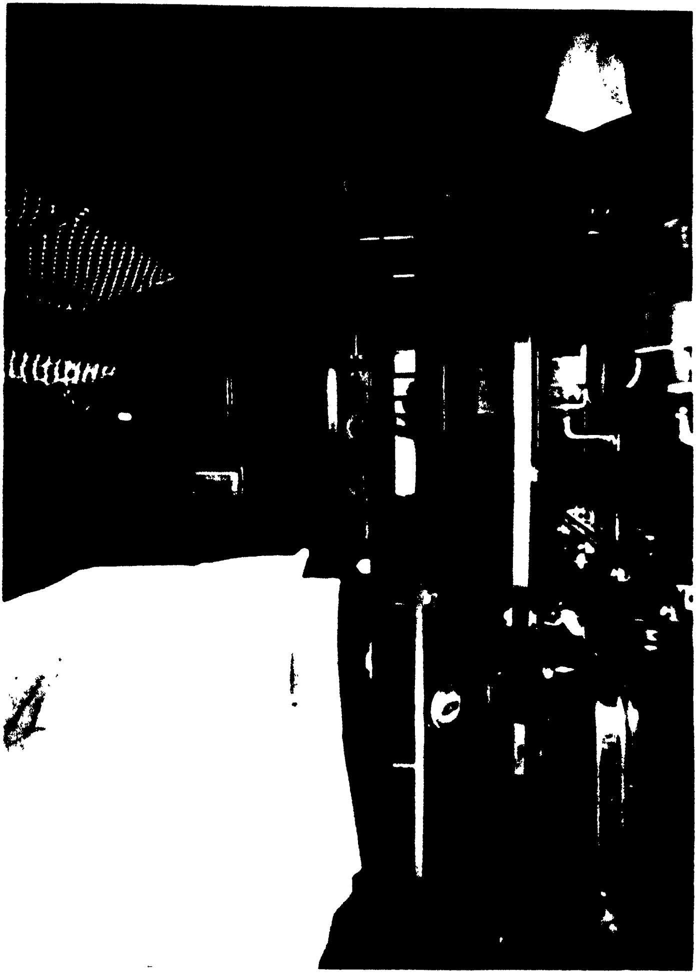
In daily service the Great Western Railway has now established what is virtually a mile-a-minute standard of running in many directions. Over the level stretch of Brunel's old West of England main line four daily runs are made at average start-to-stop speeds of over 60 m.p.h., headed by that of the 3.45 p.m. summer express from Swindon to Paddington, which, by covering the 77·3 miles in 75 minutes, lays claim to the fastest start-to-stop booking in the British Empire. As illustrating the capacity of present-

day Great Western locomotives, the writer may mention that he has in his possession the details of a run on this train in which the complete distance was covered, inclusive of attaining speed from the start and slowing down for the stop, in the astonishing time of 66 minutes 12 seconds, which represents a gain of nearly 9 minutes on schedule time. To the West of England further acceleration of the "Cornish Riviera Limited" express (Plate 114) now results in the schedule for the 173·7 miles from Paddington to Exeter having been cut to 173 minutes; allowing for the severe slowings which have to be made over the curves at Reading, Westbury and Frome, this booking entails an average rate of well over 60 miles an hour for a considerable part of the journey.

The timing of the Cornish train is the more remarkable in that loads up to fourteen of the heavy Great Western 70-ft. coaches, weighing with passengers and luggage some 525 tons and measuring up to one-fifth of a mile in length, are taken out of Paddington frequently. As this famous train proceeds westwards, and the gradients increase progressively in severity, the load is correspondingly reduced by means of slip coaches, a Weymouth portion of two vehicles being thus detached at Westbury and the Ilfracombe and Minehead coaches at Taunton, while a portion for Kingsbridge comes off at Exeter stop. When the engine reaches the formidable gradients of South Devon, which were described in detail in Chapter II, the train has therefore shrunk, except during the height of the summer, to some seven vehicles, or at most eight, which the latest 4–6–0 "Castle" and "King" class locomotives can handle without difficulty up the extremely steep ascents to Dainton and Rattery. Among British expresses the "Cornish Riviera Limited" of the G.W.R. achieves a record in the number of independent through coaches that it carries; the main

part of the train, including the restaurant car, runs to Penzance, and is followed by through carriages for St. Ives, Falmouth, Newquay, Kingsbridge, Exeter, Ilfracombe, Minehead and Weymouth, making nine portions in all. For twenty years, also, this famous express achieved the record of making the longest daily non-stop run in the world, over the 225¾ miles from Paddington to Plymouth, but this continuity was broken in September, 1928, by the insertion of a stop at Exeter.

The slip coach, to which reference has just been made, is a convenient method of setting down passengers from an express at an intermediate station without stopping the train for the purpose. A specially fitted brake coach must be employed, in the front compartment of which the slip guard, who is responsible for the severance of the train, is accommodated. The coupling of the last coach on the main part of the train is held in a hinged hook on the slip coach, and at a distance from the slipping station which is governed by the speed of the train, the gradients and other factors (generally about ½-mile away), the slip guard, by means of a lever, withdraws the sliding bar which holds the point of the hook in position, so that the hook falls and the coupling drops out. Prior to this the guard has shut off, or "sealed" the brake vacuum in his slip portion, and has applied the hand-brake lightly on the wheels of his coach, so that the slip may draw away from the main train directly the severance has been made. Automatic appliances secure the sealing of the vacuum on the main train, and the connecting hose-pipes of both the brake and the steam-heat are arranged to come apart without injury. Special tail-signals are carried on the back of the slip portion, consisting of red and white lamps encircled by discs of the same colour, the arrangement of which is varied, as shown in Fig. 18, when one, two or three slips are on the same



117.

A Modern British Sleeping Car Interior

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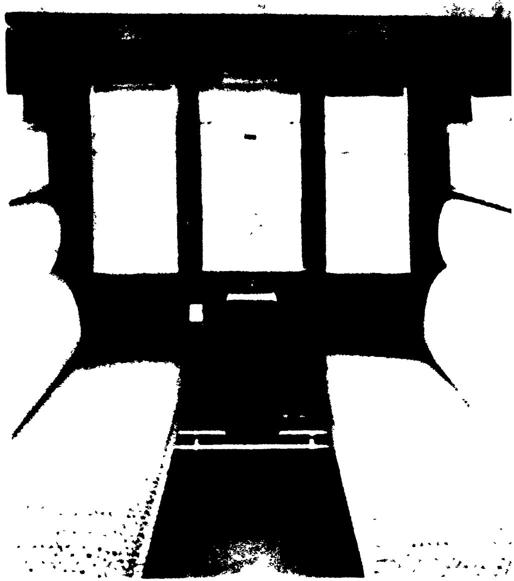
Arranged for night use.



Arranged for day use.

Q 231.

Third-Class Sleeping Car, L.N.E.R. p. 211

train. The working of slips is hedged about with the most careful restrictions, in view of the fact that, before the slip portion has come to rest, two trains are, in effect, running in the same block section at the same time ; in foggy weather or falling snow slipping is suspended altogether, and the trains concerned are stopped instead, to detach the slip portion. The disadvantage of slipping coaches is that each slip requires the provision of a slip guard and special rolling stock ; in consequence this once widely-employed means of working has now practically died out, except on the Great Western Railway, which still works some 40 " slips " daily.

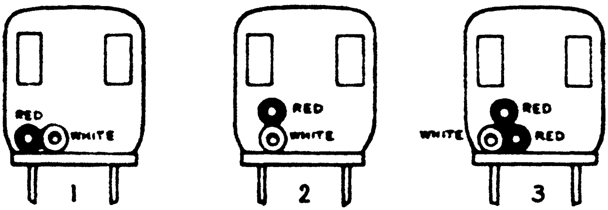


Fig. 18.—Slip Coach Tail Lamps.
1.—One " Slip " only. 2.—Rearmost of two Slip portions.
3.—Rearmost of three Slip portions.

The highest regular maximum speeds on the Great Western Railway are performed over the Birmingham route. When the G.W. short route to the North was opened, *via* High Wycombe and Bicester, it became possible to compete on more or less level terms with the then London and North Western Railway for the important business traffic between London and Birmingham. The G.W.R. has 2½ miles less in distance to travel, but this advantage is far more than offset by the greater difficulty of the Great Western route, from the locomotive point of view : the G.W.R. handicap is compounded of more severe gradients,

and, in addition, a number of severe slacks for curves, in particular at Old Oak Common (Acton), High Wycombe and Leamington. As a result, the maintenance of the two-hour schedule, which in all but two cases includes stops at Leamington or High Wycombe, makes necessary some exceedingly high intermediate speeds over favourable gradients. Maximum speeds of over 80 miles an hour are not only common, but customary, on the down journey north of Princes Risborough, and on the up journey past Bicester and Denham, and are not infrequently attained at other points also; in addition, it is usual for the expresses over this route to perform the considerably more meritorious feat of maintaining speeds well in excess of 50 miles an hour, and sometimes over 60 an hour, up long continuous stretches of 1 in 200 gradient. The writer's highest record of locomotive speed in ordinary service was secured on one of these trains, one of the 4-cylinder 4-6-0 "Star" class engines having attained the rate of 91·8 miles per hour in descending the 1 in 187 gradient from Southam Road to Leamington, with the 6·10 p.m. express from Paddington to Birkenhead, as mentioned in a previous chapter.

It may be interesting, at this stage, to mention the means by which speed figures are arrived at. Every railway is compelled, by Act of Parliament, to mark the distances over all its lines by means of posts fixed at ¼-mile intervals. On the G.W.R. these are all on the up side of the line, as also on the Midland Division of the L.M.S., whereas other railways chiefly favour the down side. An ordinary stop-watch, reading to one-fifth of a second, will give the speed over ¼-mile to within ½-mile per hour of the exact figure, even at high speeds; but the eye of the observer should be maintained steadily along the "line" of a window-frame, or other fixed object in the compartment, to obtain an accurate result If the second-hand of an ordinary

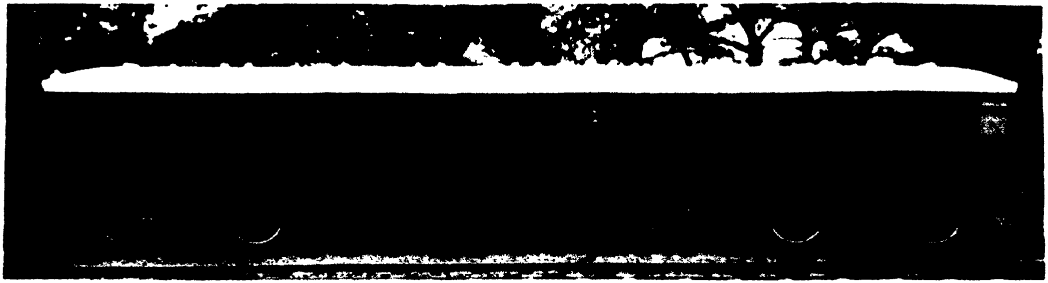
watch be employed, it is well to take the time over nothing less than a complete mile, as the fraction of time taken by the eye to travel between the mile-post and the watch may involve the observer in serious errors, especially at high speeds, if nothing longer than a ¼-mile be timed.

Another method is to calculate the distance by means of the number of rails over which the train passes, clearly distinguished by the rhythmic " jolts " as the coach passes over each joint in the rails, and to time over a definite length of track in this way. The lengths of rails chiefly in use in main lines are 60 ft. and 45 ft. ; 22 of the former and 29 of the latter go to make up one ¼-mile, so that the recorder should note the time occupied by him in counting the "jolts" from 0 to 22 or 0 to 29 respectively. But the rail-joint method, useful though it is, in particular at night-time or on occasions when the observer has not been privileged to secure a corner seat, needs a vast amount of experience of railway acoustics and of the rail-lengths, which often vary considerably, in use on the routes over which he travels, ere he can place reliance on this method of timing. Attempted ascertainment of speeds from the passage of telegraph poles is a very approximate method, and should in no circumstances be relied on to give accurate results.

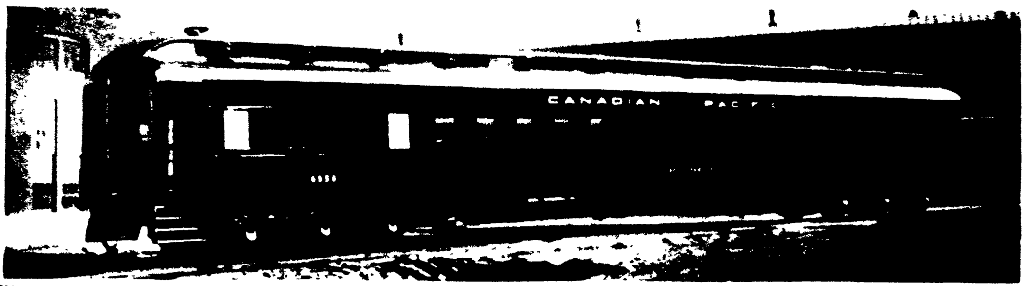
To compile a " log " of an express train journey, the recorder should note accurately the starting and stopping times, and also the times of passing each station, junction and important summit point, to the nearest 5 seconds by the second-hand of his watch, supplementing this information by details of the minimum speeds uphill and maxima downhill, obtained from mile-posts or rail-joints by means of a stop-watch. Frequent journeys, aided by the line-side gradient posts, soon familiarize the observer with the physical features of any route, and the record of train-running, and particularly the comparisons rendered possible

between the work of different types of locomotive in varying conditions of load and weather, become a very fascinating pastime. The monthly series of articles entitled "British Locomotive Practice and Performance," which the writer has himself conducted continuously in the *Railway Magazine* since 1909, deals largely with this subject of locomotive performance, and to those who wish to follow up the subject should give no small help in acquiring the route familiarity on which stress has just been laid.

Next to the Great Western Railway in the matter of high scheduled speeds comes the London and North Eastern, and, as will be seen by the table of fastest British runs, which constitutes Appendix H, the Great Central section of the L.N.E.R. is responsible for a number of the best efforts in this direction. Three of the runs tabulated are made by the same train—the newspaper express leaving Marylebone at 2.32 a.m.—and are the more difficult of maintenance in that the distances covered are so short, as well as including considerable lengths of adverse gradient. These and other extremely fast timings over the G.C. Section of the L.N.E.R. could not be maintained were it not for the light loads carried by most of the expresses, seldom exceeding 250 tons at most; and even then high speeds, frequently up to 80 m.p.h., are necessary on the falling gradients in order that time may be kept. The fastest intermediate booking over this section is that of the 6.20 p.m. Bradford express out of Marylebone, which is timed to run the 71.6 miles from passing Princes Risborough to the Leicester stop in 69 minutes. For many years the L.N.E.R. Darlington to York run of the Glasgow-Leeds "diner"—44.1 miles in 43 minutes—held the British record for speed, until displaced by the G.W. Swindon-Paddington run; it is made over an almost dead level course, but the slow approach round the curves to



8-wheeled British [illegible] class sleeping car, tare 3[illegible] tons (p. [illegible])



Pl. 110. S. 234

12-wheeled Canadian Pacific cafe parlor car, length 7[illegible] ft., tare 7[illegible] tons (p. 218)

British and American Coach Design (p. 12[illegible]).

Dining Car, Canadian National Railways (p. 210)

A fine example of modern American interior coach decoration

York makes necessary an average rate of round about 70 miles an hour over the 25 miles from Northallerton to Beningbrough.

Over the East Coast main line of the L.N.E.R. generally, though no exceptionally fast timings are in force, other than that just mentioned, the haulage problem is a combination of substantial loads with reasonably high speeds. The heaviest outward-bound train from London is the 4 p.m. express, with sections for Woodhall Spa, Cleethorpes, Leeds, Bradford, York, Scarborough and Newcastle; this generally loads to at least sixteen vehicles, weighing with passengers and luggage some 525 tons, but the "Pacific" locomotives employed never require to take pilot or banking assistance. It is, however, no unusual thing for the East Coast trains of the L.N.E.R. to be made up to loads of over 500 tons when traffic is heavy, and time has been kept by the L.N.E.R. "Pacifics" with 600-ton trains.

Most famous of the East Coast expresses is, of course, the "Flying Scotsman" (Plates 123 and 124), which has created a record of an unusual kind with an unbroken departure time at 10 a.m. from both King's Cross and Edinburgh for over sixty years, since 1865. During the summer of 1928 this express inaugurated the additional record of making the longest non-stop run in the world, covering the 392¾ miles between King's Cross and Edinburgh, in both directions daily, without intermediate stop. Engine-crews were changed *en route* by way of the corridor tenders previously described, and novel additions to the comfort of passengers have been found in the provision, for the first time on a British train, of a barber's shop, a retiring room for ladies, with a ladies' maid, and the sale on board of newspapers, magazines and books. But no longer does the "Flying Scotsman" hold any speed record; the Leeds expresses, in fact, "fly" considerably

faster over the same main line between London and Doncaster. There has been an agreement in force between the East and West Coast Companies since the 'nineties that the time by the day trains between London and Edinburgh and Glasgow shall not be cut below 8¼ hours, and this is still rigidly adhered to.

The tragedy is the greater in that, as far back as 1888, when the two rival routes were racing to Edinburgh, the East Coast time was brought down to 7 hrs. 27¾ min. from King's Cross; while in the far more thrilling "Race to Aberdeen" of 1895, which succeeded the opening of the Forth and Tay Bridges, and the access to popular favour of the East Coast Route, the time from King's Cross to Edinburgh was cut to 6 hrs. 18 min. Aberdeen was reached in 8 hrs. 40 min. from King's Cross, on the night of August 21st, 1895, after some marvellous running, whereas the fastest public time to-day is one of 12 hours. These facts speak for themselves, and witness to the crying need for material acceleration of our chief Anglo-Scottish train services, which do not so much as attain to a 50-miles-an-hour standard from end to end. Much faster running is made by the "Queen of Scots" all-Pullman express (Plate 48), which travels to Scotland by way of Harrogate, and makes a non-stop run over the 185¾ miles between King's Cross and Leeds. Both this train and the "West Riding Pullman" (Plate 81), which covers the 175¾ miles between London and Wakefield without a stop, are booked to run the 138¾ miles between Hatfield and Doncaster in 140 minutes, at an average speed of all but 60 miles per hour.

The best average speeds of the London, Midland and Scottish Railway are achieved on the London and Birmingham service, in competition with the Great Western. As in the case of most of the G.W. two-hour Birmingham expresses, so also all but two of the L.M.S. trains make inter-

mediate calls, which have the effect of raising the average speeds. The best of these timings are embodied in the schedules of the 9.10 a.m. down from Euston and the 4.50 p.m. from Birmingham, both of which cover the 107½ miles between Willesden Junction and New Street, Birmingham, in 109 minutes, at an average start-to-stop speed of 59.2 miles per hour. On the West Coast main line, however, the bulk of the trains are slower, but at the same time considerably heavier. Of these the most notable is the famous "Royal Scot" express (Plates 68 and 128), to which references have already been made. This modification of the working of the well-established 10 a.m. Scotch express out of Euston was first put into force in July, 1927, when the "Royal Scot"—really the first portion of the 10 a.m., conveying passengers for Glasgow and Edinburgh only—was altered to make its first call at Carnforth, 236 miles from Euston. Here engines were changed, and a second pair (the train was, at first, double-headed throughout) worked through non-stop, over both Shap and Beattock Summits, to Symington, 130 miles further on. At Symington the Edinburgh portion was detached from that for Glasgow, and the brief final runs of each portion concluded the summer journey of the "Royal Scot."

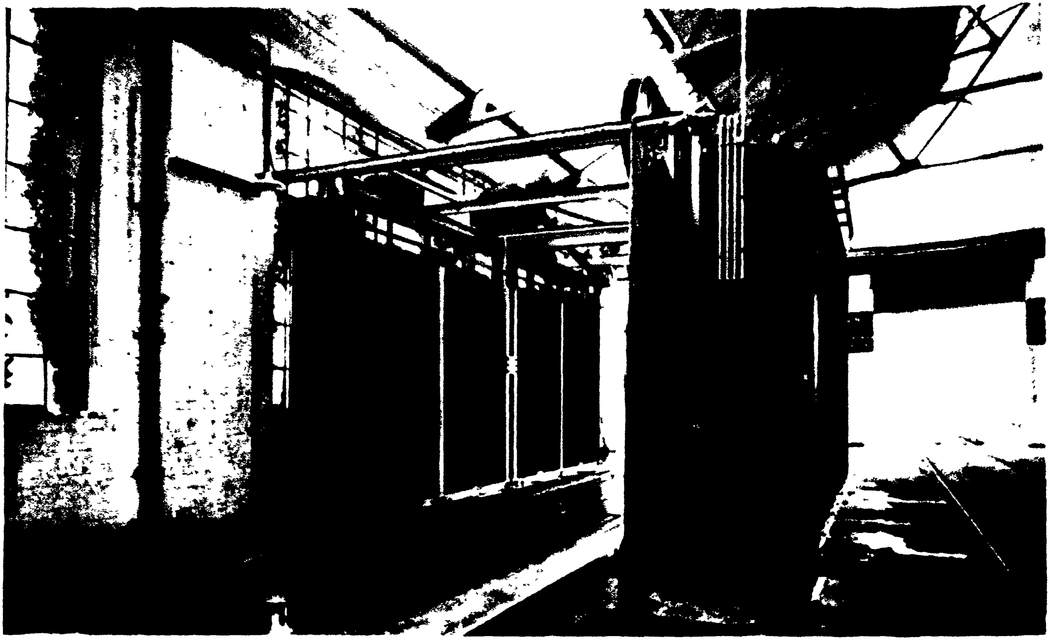
From the beginning of October, 1927, however, the introduction of the new "Royal Scot" 3-cylinder 4-6-0 engines enabled the Carnforth stop to be cut out, the train finally making a non-stop run of 300¾ miles between Euston and the Kingmoor locomotive sheds at Carlisle, where a second "Royal Scot" engine replaced the first. At the same time double-heading, or pilot assistance, was dispensed with, the new locomotives being of sufficient power to work the 14-coach or 15-coach summer formation of the "Royal Scot," weighing with passengers and luggage 410 to 440 tons, up the steep inclines to both summits without

help. For the winter of 1928, however, the previous stops of this express at Rugby, Crewe and Carlisle were resumed.

Although the establishment of daily non-stop running over 300 miles constituted a world's record of no mean order, the run had actually been made on three previous occasions. As far back as 1897 one of the Webb 3-cylinder compounds, named " Ionic," ran from Euston to Carlisle without a stop, and this was followed, in 1902, by non-stop running in both directions, with a special train conveying delegates to and from the International Telegraph Conference, the engines concerned being the 4-cylinder Webb 4–4–0 compounds " C. H. Mason " and " Commonwealth." A list of the longest daily non-stop runs in Great Britain is given in Appendix G.

In the matter of time, of course, the present 5¾-hour schedule to Carlisle of the " Royal Scot," cut as it has been on one occasion to 5½ hours, far from establishes a record. In the 1895 Race to Aberdeen, the West Coast racing train—the 8 p.m. out of Euston—on the last night of the contest reached Carlisle in just over 4½ hours, and actually covered the 540 miles from Euston to Aberdeen, stops at Crewe, Carlisle and Perth and the negotiation of Shap, Beattock and Gleneagles Summits all included, in the astounding time of 512 minutes, involving an inclusive average speed of 63.3 miles per hour for the whole distance. The weight of the train, it is true, was only 70 tons, all told, but in view of the vast subsequent increases in locomotive power and efficiency, the present best time of 5¾ hours to Carlisle and 12 hours to Aberdeen is far from adequately explained by the difference between the train-weights of 1895 and those of to-day.

One important L.M.S. express to which the ordinary passenger is not admitted is the " West Coast Postal,"



Pl. 121. O 238

Automatic Carriage-Washing Plant, Ealing Common, Metropolitan District Railway (p. 224)

The coaches are passed between the revolving mops seen on left hand side of track

leaving Euston for Scotland at 8.30 p.m. daily. The night postal business of the West Coast route is of sufficient magnitude to call for the running of this special train, consisting of twelve or more vehicles. Several of these are "sorting tenders," in which the work of letter-sorting and despatch goes on actively throughout the night. At the more important stations and junctions, such as Rugby, Tamworth, Crewe, Preston and Carlisle, the train is stopped for the purpose of receiving and delivering large consignments of mail matter, but the service to and from intermediate places is carried out by means of the mail apparatus. At suitable points by the lineside, within easy reach of the town or village concerned, a tall standard is erected, together with a large ground-net made of some of the strongest rope obtainable. The bags of mail matter intended for the train are brought to this apparatus by a postman, are secured in stout leather pouches, and hung from the standard, which is swung out towards the line just as the "Postal" is due. Meanwhile the train staff have similarly bagged and pouched the correspondence destined for this particular place, and have hung the pouches from extending arms on the side of the sorting coaches; a large folding net on the side of one of the latter is also opened out. As the train passes the ground apparatus, the exchange is made, in a flash, the bags off the train being caught in the ground-net, while those off the ground standard are as neatly picked up by the train net. The apparatus and method of exchange are illustrated in Plate 122. A large number of such exchanges is made throughout the night, each new consignment of letters and parcels being sorted as the train proceeds; the work of sorting, in such conditions, requires great mental concentration and a high standard of physical fitness, picked men alone being employed to form the train-crew. The only other British

express conveying mail matter exclusively is the G.W.R. West of England mail leaving Paddington at 10.10 p.m. for Penzance, with the corresponding return train, but a number of other express trains, both by day and night, carry mail-vans and sorting tenders, and in addition to this huge quantities of postal matter are conveyed in the luggage-vans of ordinary trains.

The highest maximum speeds on the L.M.S. system are, as a general rule, attained on the Midland Division. The Midland main line is similar to the Great Central Section of the L.N.E.R. in the steepness of its gradients, and many of the timings—particularly those in force south of Leicester and Nottingham—involve very high maximum speeds. Such schedules as 107 min. for the 99 miles from Leicester to St. Pancras, or 135 minutes for the 123½ miles between Nottingham and London, are no mean achievements for the 4–4–0 3-cylinder compound locomotives invariably employed, hauling loads over this heavily-graded road that are frequently in excess of 250 tons. But overall Midland times and speeds suffer in consequence of the numerous halts which must be made even by the best trains, such intermediate cities as Leicester, Nottingham, Derby Sheffield and Leeds being of too great importance, save in the case of one or two special expresses, to be given the "go-by," let alone Bedford, Kettering, Chesterfield, Rotherham and other large towns which also demand a good service. For this reason 100-mile non-stop runs over the Midland system are but few in number, as compared with the numerous lengthy non-stop journeys over the Western Division of the same railway. On the Scottish sections of both the L.M.S. and L.N.E. Railways, the same conditions obtain in a still more accentuated form, the fast train services themselves being of less frequency than in England, and this fact, coupled with the extremely difficult gradients of

the Scottish main lines, results in but little in the way of either high speed or lengthy non-stop runs being achieved in Scotland.

Of all the British groups, it is probably the Southern which has made the greatest strides of recent years in the matter of speed. There was doubtless some leeway to make up, as compared with the other chief British main lines, but in consideration of the congested exits of all the Southern main lines from London, and the great difficulty of some of their gradients, the speeds over many of the Southern routes are remarkable. On the West of England main line, for example, the 90-minute schedule of the "Atlantic Coast Express" from Waterloo to Salisbury is maintained over a journey of 83¾ miles, despite gradients which are mostly adverse for the first 50 miles out of London, after which maximum speeds of 75 to over 80 miles an hour are common enough, both at Andover and down the approach to Salisbury. The corresponding up journey includes an allowance of only 41 minutes for the 44 miles between passing Basingstoke and Clapham Junction, shared in common with certain other up expresses, and it is nothing unusual for the "King Arthur" 4-6-0 engines to maintain average speeds up to and even over 70 miles an hour for over 30 miles of this stretch, until the engines have to be eased on account of the busy approach to Waterloo.

West of Salisbury, notwithstanding gradients of ever-increasing severity, which culminate in the terrific 7-mile ascent to Honiton Summit, including 4½ miles right off at 1 in 80, the best timings are only 97 minutes in both westbound and eastbound directions for the journey of 88 miles. This average speed of 54·5 miles an hour is probably without parallel in any part of the world, over grades of such severity, and in both directions of running maximum speeds of over 80 miles an hour, at the bottom of the various descents, are

making great strides in the matter of speed and of locomotive performance. In connection with the 10.45 a.m. Pullman express from Victoria there runs the French "Golden Arrow" (Plate 127), covering the 184½ miles from Calais to Paris in 190 minutes. The chief merit of this achievement lies in the weight of the train, which with its full complement of ten 48-ton Pullmans and a luggage van weighs 520 tons behind the tender; further, the tender itself, owing to the absence of water-troughs from the French railway systems, has to be of enormous size and weight, in order to carry sufficient water for this long run. Yet again, out of Calais there is a rise for 8 miles at 1 in 125 to Caffiers, equal in length and steepness to the worst of our northern approach to Shap Summit, followed by gradients that in places are not inconsiderable, especially before Etaples and up from Creil up to Survilliers. Reductions of speed must be made through Boulogne and Abbeville, and a very severe slowing through the sharply curved station at Amiens. When all these hindrances have been allowed for, it is left to the remarkable 4-cylinder compound "Pacific" engines of the Nord (Plate 80) to maintain average speeds of approximately 70 miles an hour over practically all the level part of the journey—from Etaples to Amiens—and up gradients of 1 in 200 (similar to the ruling grade of the L.N.E.R. main line south of Grantham) the minimum rate, with 520 tons, must be well above 50 miles an hour. On the outward journey to Calais, the "Golden Arrow" is allowed only 156 minutes in which to cover the 156½ miles from Paris to passing the Outreau Junction at Boulogne.

These are but two examples of the extraordinarily fast running performed on the Nord Railway of France, in many cases with trains of great weight; Appendix I. makes it clear that the Nord must be credited with 29 out

Pl. 124. *R* 244.

The 392¾ miles Non-stop Flight of the "Flying Scotsman," L.N.E.R. (p 235)

"Pacific" Engine No 4472, "Flying Scotsman," and train passing Newcastle-on-Tyne

Pl. 125. R 245.

70-ft. Steel-Panelled Third-Class Corridor Coach, Great Western Railway (pp. 218, 221).

of the 34 fastest runs in France, including the fastest run in the Continent of Europe, the 12.15 noon express from Paris to Berlin now being booked to cover the 95·1 miles to St. Quentin in 92 minutes, start-to-stop, at an average speed of 62·1 m.p.h. The next fastest run is on the Midi line, in the south of France, which works the Sud express over the 91·8 miles from Bordeaux to Dax in 89 minutes, at an average start-to-stop speed of 61·9 m.p.h. and has a second express booked to cover the same distance in 91 minutes; it is of particular note that the haulage in these two latter cases is performed by electric locomotives.

Next to the Nord, in point of speed, come the Est and Paris-Orleans lines. On all these three it is no uncommon occurrence to travel at speeds up to 120 k.m. (74 miles) per hour—the legal maximum railway speed limit in France and Belgium—over level track, hauled by the compound "Pacific" locomotives which are in general use in France. The Sud Express, running over the Paris-Orleans line from Paris to Bordeaux and thence over the electrified Midi, is timed at an average speed of 51.7 miles per hour from Paris over the 482½ miles to Bayonne, all stops included; the special night Swiss express from Calais makes its cross-country journey over the 432½ miles between Calais and Belfort at an average of 50·1 miles per hour, which is faster for the distance covered than our Scotch expresses of either the East or the West Coast Routes.

The giant system of the Paris, Lyons and Mediterranean Railway—or, more familiarly, the "P.L.M."—does not specialize to the same extent in high speed, but its procession of expresses out of Paris each night, several of them *trains-de-luxe* and many conveying first-class passengers only, for destinations in all parts of southern Europe, has probably few parallels in any part of the world. Owing to the great weight of many of these trains, the P.L.M. Company has

recently experimented successfully with a new type of 4–8–2 express locomotive, and with such success that some 90 of these engines are being built. The experiments included high speed haulage of a train of 645 tons, later increased to the enormous figure of 810 tons. The standard rostered loading for engines of this type on express trains is now 600 tons. It may be added that the longest non-stop run on the Continent of Europe is made by the all-Pullman "North Star" express, which runs through between the two capitals of Paris and Brussels, a distance of 192½ miles, without stopping in either direction, Customs examination of passengers' luggage taking place on the train.

The vast spaces of the American Continent, and the lengthy journeys of American trains, have neither been productive of exceptionally long non-stop runs nor of very high average speeds. Of all non-stop journeys regularly made, the longest without a break is that of the "Twentieth Century Limited," over the 182 miles between Buffalo and Cleveland, which falls far short of the maximum achievements of British railways. But in the matter of speed there are certain factors which explain what are apparently low average rates of travel. In many American towns and cities, the railway tracks are either carried through the streets, or are at least intersected by numerous level crossings, both of roads and of other railways. Constant reductions of speed are therefore necessary on many routes, and the work of the engines consists in large part of rapid acceleration from such slacks to high intermediate speeds—which on certain high-speed routes reach maxima of as much as 80 m.p.h. as frequently as in this country—followed by a reduction of speed for the next slack. When this fact is coupled with the enormous weight of many American express trains, which, with the all-steel rolling stock now in

use, may and often does exceed 1,000 tons per train, the merit of much of the American express train running is greatly enhanced.

The fastest American timings are, for the most part, found on the Philadelphia and Reading and the Pennsylvania lines between New York and Philadelphia, and also between Philadelphia and the popular seaside resort of Atlantic City. On the former route the distance between the two cities is covered in the even two hours, and after allowance has been made for slow running in the environs of both cities, some very fast travelling has to take place intermediately. Such timings as 27 minutes for the 27·2 miles from Bound Brook to Trenton Junction, and 21 to 23 minutes for the 22 miles between Trenton and Jenkintown are common, in each case involving start-to-stop average speeds of 60 miles an hour and over, despite the shortness of the distances.

Similar timings prevail between Camden City (Philadelphia) and Atlantic City. At one time, before the war, the throughout journey from Philadelphia to Atlantic City by the Philadelphia and Reading route was performed in 60 minutes, and as 10 minutes of this time were occupied in ferrying across the river, it left to the locomotives the task of covering the 55½ miles from Camden City to Atlantic City in 50 minutes. The timekeeping of these trains was extraordinarily good, and not infrequently time lost in crossing the river was made up by the locomotives. The fastest run on record was made in May, 1905, when the journey of 55½ miles was completed with a 280-ton train in the astounding time of 42 min. 33 sec., at an average rate of 78.3 m.p.h. from start to stop—one of the most rapid runs ever performed by a steam locomotive. To-day, owing to the greatly increased weight of the train concerned, which now loads to 12 cars weighing 645 tons, the time is

increased to 55 minutes. The best timings by the Pennsylvania route of 58·4 miles are 58 min. from Camden to Atlantic City, and 59 min. in the reverse direction. In various other parts of America fast times are made, the Michigan Central being a noteworthy line in this connection, the best timings are those of the "Detroiter," which covers the 112½ miles between Windsor (Detroit) and St. Thomas in 113 min., in one direction, and 115 min. in the other. Canada, too, is developing a taste for railway speed, arising out of the competition between the Canadian Pacific and the Canadian National Railways for the important traffic between Montreal and Toronto.

But the chief feature of American passenger services is the long-distance train-running. Many of these expresses, crossing the Continent from east to west or north to south, are travelling hotels, containing not only every convenience for eating and sleeping, but carrying also libraries, club cars, observation cars, stenographers and typists, barbers, valets and ladies' maids! Most famous of American trains are probably the competing "Twentieth Century Limited" of the New York Central Lines, and the "Broadway Limited" of the Pennsylvania Lines, both of which run between New York and Chicago in 20 hours. The former covers a fairly level route of 978¾ miles, up the Hudson Valley to Albany and then along the south shore of Lake Erie; whereas the latter, over a distance of 908 miles, has to make its way through the Alleghanies and other hilly districts. For a short period the time was cut to 18 hours, by both expresses, but the accelerated schedule proved too costly to maintain. Both trains are very popular; the "Twentieth Century Limited" runs nightly in at least three and sometimes five parts, a striking view of one of which, hauled by a "Hudson" type 4–6–4 express locomotive, appears in Plate III. The Canadian

National Railways have their own wireless broadcasting service, from a chain of stations extending across the width of Canada, for transmitting wireless programmes to the trains, and also serving as the means of communication to the staff all over that great system, many of them located in very remote places. In Plate 113 is seen a radio-equipped day coach on the "International Limited" Express, the wireless receiver and the headphones for passengers' use being clearly visible. The competing Canadian Pacific Express—the "Trans-Canada Limited"—is seen among the Rockies in Plate 130.

As this chapter has already far exceeded the limit of the writer's intentions, owing to the interest of the subject with which it deals, there is no space left in which to describe the express train services of other countries, though it can be claimed that the world's fastest and most luxurious express trains have, in general, been mentioned in the foregoing remarks. Long-distance railway passenger service has made great strides in the matter of comfort and convenience during the last quarter-of-a-century. It only remains now for attention to be paid to the matter of speed, with a view to bringing our railways more into line with present developments in the speed of road and air transit. And it may be claimed, with but little fear of contradiction, that whatever demands may be made on our magnificent modern express locomotives in the matter of reasonable acceleration of express trains will find them fully prepared to respond.

CHAPTER XIII

Branch and Cross-Country Services

OF all the problems which face British railway officers, there is probably none which gives greater concern than the problem of branch line operation. It is not too much to claim that the majority of railway branches in country districts are worked at a loss, their only value to the railways being the extent to which they "feed" the main lines. On the one hand, the vast spread of motor transport, both of passengers and of merchandise, has taken away a large proportion of the branch traffic. The road motor has the great advantage of offering door-to-door transit, whereas passengers by rail have to proceed to and from the stations, and merchandise must (apart from the use of the "container" wagons described in Chapter XV) be carried to and from the goods depots and there transhipped both into and out of the wagons, which process is costly both in time and labour. Again, the road motor-bus or the lorry can be worked by a single man, whereas the locomotive-hauled steam train requires a driver, a fireman and a guard. Yet again, the railway is charged with the costly maintenance of its permanent way and its stations, as well as the provision and working of the signalling which it is under legal compulsion to provide, whereas the owner of the motor or the lorry, once he has paid the tax on his vehicle, governed by its horse-power, and on his petrol, is faced with no further expense in connection with the upkeep and the policing of the roads of which he makes free use, let alone with the cost of providing the highways in the first instance.

To make matters worse, the railways, as the heaviest

ratepayers in many of the districts through which they pass, by contributing so largely to the upkeep of the roads used by their competitors are virtually in the position of subsidizing the latter, to whom their own traffic is being lost. Insult was added to injury in that—with the exception of a few limited powers granted to independent railways before the grouping took effect in 1923—the law did not permit the railways to go out on to the roads with their own motor vehicles to meet this fierce competition, although some redress of this anomaly has now been obtained. And if this were not enough, the Parliamentary compulsion on British railways to keep the hours of all their staff down to not more than eight per day operates with the greatest severity on branch lines, some of them with but two or three trains a day ; whereas the hours of the men working motor omnibuses and lorries are without any corresponding restriction.

Main lines, though attacked, are not yet quite so badly hit, as the railway still holds its own as the safer, the quicker, and, on the whole, the more comfortable medium for long-distance travel—compared with the road—and also as the only satisfactory method, as yet, for the conveyance of heavy freight, such as coal, in bulk over long distances ; further, the continuous day-and-night traffic over many of our important main lines is quite sufficient to justify three 8-hour shifts of working per day for the staff. The suburban traffic round our large cities also holds its own still, especially where the railways have been electrified, the congestion of the roads during the " rush " hours, with its proportionate slowing down of the road services, being enough to keep the suburban travellers faithful in the main to railway transport. But in the working of country branch lines, all the handicaps which have been mentioned are felt to the full. In a few instances

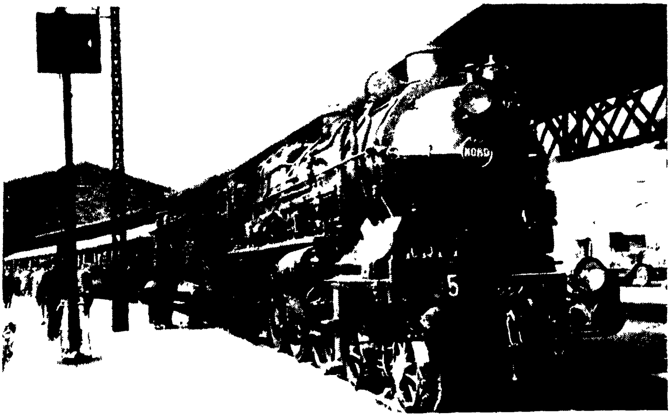
the drastic step has been taken of closing branches altogether, and of pulling up the track. But elsewhere the aim has been to cut down to the very minimum the cost of branch line operation.

The problem has been approached in various ways. By the use of corridor passenger stock, provided with gangways, it is possible on a number of branches for the guard of the train to issue and collect the passengers' tickets, thus dispensing with booking offices and booking clerks at the intermediate stations. Some of the smallest stations and halts are left in the charge of a single man, and other intermediate stations are often staffed by two or three only, one stationmaster supervising the whole of the stations on a branch, provided it is not of undue length. Where branch lines are run as "light railways," with certain statutory restrictions as to maximum speed, it is unnecessary to provide level crossing gate-keepers at the points where the railway crosses public roads on the level, this being a further minor source of economy.

But the chief developments in branch line working have concerned the motive power. As far back as 1848, the late Mr. W. B. Adams designed for the Bristol and Exeter Railway a combined engine and coach for short distance work, and followed this up in 1849 with the rail motor coach "Enfield," which was put to work between London, Stratford, Edmonton and Enfield by the Eastern Counties Railway; this was in the days before the north-eastern suburbs of the Metropolis had become the "dormitory" for so large a proportion of London's workers, and when the traffic was relatively small. The idea found little support at that time, however, and remained more or less dormant until the beginning of the present century, when between 1903 and 1907 there was a sudden and widespread outbreak of "rail motor-car" construction. Almost every one of

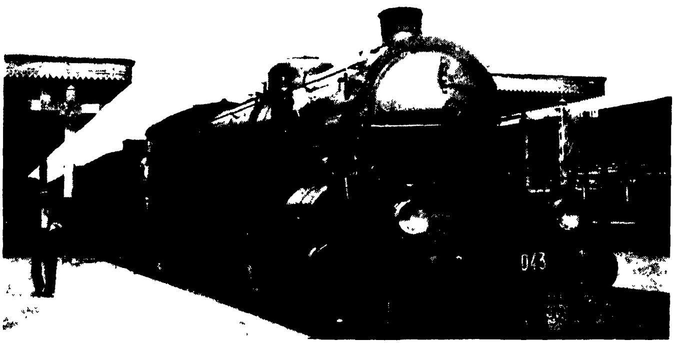
Pl. 126. *R* 252.

Saloon Coaches of "Rheingold Express," German Mitropa Co. (p. 213).



"Golden Arrow" Pullman Express leaving Paris, C. de F. Du Nord France (p. 244).

Hauled by "Super-Pacific" 4-cyl. compound express locomotive.



Photos by] [*W. H. C. Kelland.*

Pl. 127. *R* 253.

Milan Express leaving Rome, Italian State Rlys.

Hauled by "Pacific" 4-cyl. compound express locomotive.

the large British railways built a number of units of this type; the principle of construction was that of a long bogie coach, with a small two-cylinder engine—generally, but not always, completely enclosed—arranged to drive one of the two bogies, which for this purpose had both axles coupled. In most cases the engine was provided with a locomotive-type boiler, necessarily of diminutive size and very short, which led to somewhat inefficient use of fuel by these rail-motors.

But more damaging objections were that any slight casualty to either the locomotive or coach portion of the rail-motor was likely to put the whole unit out of commission, making necessary the finding, at short notice, of both a substitute locomotive and a substitute coach or coaches; while the engines themselves were of insufficient power to haul more than the coach body to which they were permanently attached, with the result that any sudden and unexpected rush of passengers could not always be coped with by the addition of "trailer" coaches. As a result of these difficulties, which were experienced to the full as soon as the rail-motor came into general use, the practice of building rail-motor cars soon fell again into disuse, and only the Great Western Railway has specialized extensively in this type of vehicle. The Great Western motors are of sufficient power to tackle the haulage of trailer coaches, and a motor and trailer in this case, both exceeding 70 ft. in length, have very substantial passenger accommodation. An alternative solution, by the late London and South Western Railway, consisted in the building of special rail-motor locomotives, of the 2–2–0 and 0–4–0 types, diminutive in size but independent of the coaches, which got over the objection of a defect in either engine or coach-body putting both out of use, and permitted a certain "flexibility" in the matter of load. Arrangements were

made so that the complete unit, when coupled together, could be driven either from the engine or from one of the coaches, in order to avoid the necessity for the engine "running round" the train at the end of each journey.

Although no further engines of this special type were built by the L. & S.W.R., it was probably from this beginning that there sprang the idea of the "motor-train," or "push-and-pull" train, which has since come into wide use in this country for the working of branch and local lines. The method of working a "push-and-pull" train is exactly the same as that just mentioned. The general practice is to fit for this type of working engines which are no longer of sufficient power for ordinary suburban passenger traffic, but which have not yet reached the end of their useful life. The coaches employed can be either of ordinary types, or, on the other hand, specially built, particularly if a corridor type of coach be desired, for the purpose of issuing tickets *en route*. From one to a maximum of six coaches, according to the traffic likely to be conveyed, are employed in the "push-and-pull" formation, the engine being arranged at one end of the train, if there are one, two or three coaches, or in the centre, in the case of four or six; the latter figure is exceptional, and represents the largest number ever so worked.

The outermost coach is provided, at its outer end, with a driving compartment, fitted with controls which work the regulator, the brake, the whistle, and in some cases the reversing gear also, as well as with speaking communication to the footplate, all of which are carried through the coaches intervening between the driving compartment and the engine. When the engine is leading, the train is driven from the footplate; when the engine is in rear, pushing the coaches, the fireman is left on the footplate, and the driver works the train from the leading coach. If the engine is

in the centre, both pushing and pulling, driver and fireman are separated continuously. As with the rail-motor, so the push-and-pull train enjoys the advantage of requiring no running of the engine round the train at terminals, which makes it possible to schedule very quick "turns-round" at the end of journeys, with no more time allowed than is necessary for the driver to walk from one end of the train to the other.

The continued and increasing loss of branch line passenger traffic, in recent years, has forcibly directed further attention to this problem of motive power; this, in its turn, has compelled a reconsideration of the motor-coach solution of the problem, and motor-coaches of special types are again being extensively built. It is outside the railways themselves that the most fruitful ideas have been evolved. Most prominent among the designs now coming into use is the Sentinel-Cammell type of car (Plate 139), in which a modified steam engine of the Sentinel type, developed in connection with steam-driven road lorries, is combined with a light steel body integral in its design with the coach underframe. Steam is provided from a vertical boiler carrying the high working pressure of 275 lb. per sq. in., and this factor, coupled with the ingenious design of the engine and the extremely light weight of the coach itself, makes this type of coach exceptionally economical in running. On the railway system of Jersey, for example, the introduction of Sentinel-Cammell cars in place of the previous steam locomotives and trains has reduced operating costs by roughly one-half. These cars are capable of very rapid acceleration from rest, so being suitable for services with many stops, and as regards speed, on the other hand, the Sentinel-Cammell cars have proved themselves to be good for 40 miles per hour continuously without difficulty. The London and North Eastern Railway has now in service or

on order a number of steam rail-cars, both of this and of the somewhat similar Clayton type, and is seeking to direct attention to the amplified short-distance services thus made possible by painting the cars in gay colours, as shown in Plate 139, and naming them after famous road coaches of pre-railway days.

In the latest geared type Sentinel-Cammell cars (Plate 133), the even higher working pressure of 300 lb. per sq. in. has been adopted, steam being led from the vertical boiler in the driving compartment (Plate 131) to a six-cylinder engine, illustrated in Plate 132. The valves are of the poppet type, actuated by cams, and all wearing parts, which are lubricated under pressure, are proportioned in such a way as to allow of exceptionally long life without attention or adjustment. By means of gearing, through a crankshaft common to all six cylinders, the power is transmitted to the driving bogie (Plate 132). This type of car, which weighs only 28¾ tons in working order, seats 59 passengers, and there are hand-straps for 20 more, at times of pressure. The coal capacity of 1½ tons is sufficient for 300 miles continuous running, and the water supply of 315 gallons lasts for 60 miles. A maximum speed of 55 miles per hour has been attained with a car of this pattern.

Other experiments in connection with branch line working have concerned the substitution of the internal combustion oil engine for the steam locomotive as the motive power. The petrol motor has been adapted in various ways to the needs of the railway. For some time the London and North Eastern Railway has had in service, on its local lines round York, a couple of motor-omnibuses of the Ford type, fitted with flanged wheels for running over the railway, and so arranged as to allow of being driven from either end. The petrol motor has the obvious advantage over the steam locomotive of being ready for service at any moment, with-

From photo by]

Pl. 128.

West Coast Expres

The train has just passed Oxenholme, and is negotiating the first stage of the 3-cylir

[F. R. Hebron.
R and S.

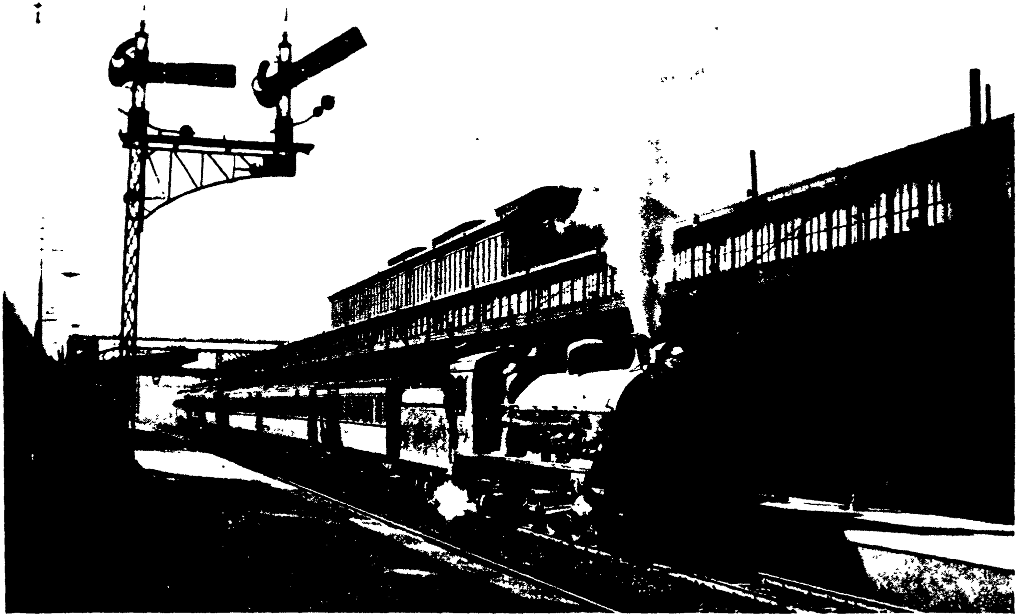
igg Bank, L.M.S. (p. 237).
Shap Summit from the South side. The engine is No. 6124, "London Scottish," of
oyal Scot" type.

out any lengthy time spent in advance in "lighting-up" and raising steam; neither is there any expense occasioned —as there is with the maintenance of a locomotive fire— when the motor is standing, between its turns of duty. Nevertheless, when all the costs of running and maintenance have been taken into account, it has yet to be proved that any ultimate economy arises from the substitution of the petrol motor for the steam locomotive in this way. In Switzerland and Russia extensive experiments have been made with the adaptation of the Diesel engine for railway work, and appear to have met with considerable success. The advantage in the case of Russia is the greater in view of the ample resources of oil that that country enjoys in the Caucasus region.

A recent British application of combined petrol-electric coach propulsion is illustrated in Plate 134, which shows a complete Diesel-electric motor-train supplied by the well-known Scottish firm of Beardmore to the London, Midland and Scottish Railway for service along the coast route between Blackpool and Lytham. Crude oil is employed in an internal-combustion engine of the Diesel type; this is coupled to a dynamo, generating the electricity which is the medium of working the car, by means of an ordinary motor. The engine-room of the motor-coach is shown in Plate 135, the Diesel motors being in the foreground, and the dynamo, to which they are direct-coupled, in the extreme background. An exhaustive trial of this Diesel-electric method had already been made on the Canadian National Railways with a couple of cars similarly driven, one of which—an articulated vehicle—figures in Plate 134. Among various tests that were made, the hardest was to drive the non-articulated car right across Canada for 2,937 miles from Montreal over the Rockies to Vancouver. During the whole of this journey the engine of the car was never

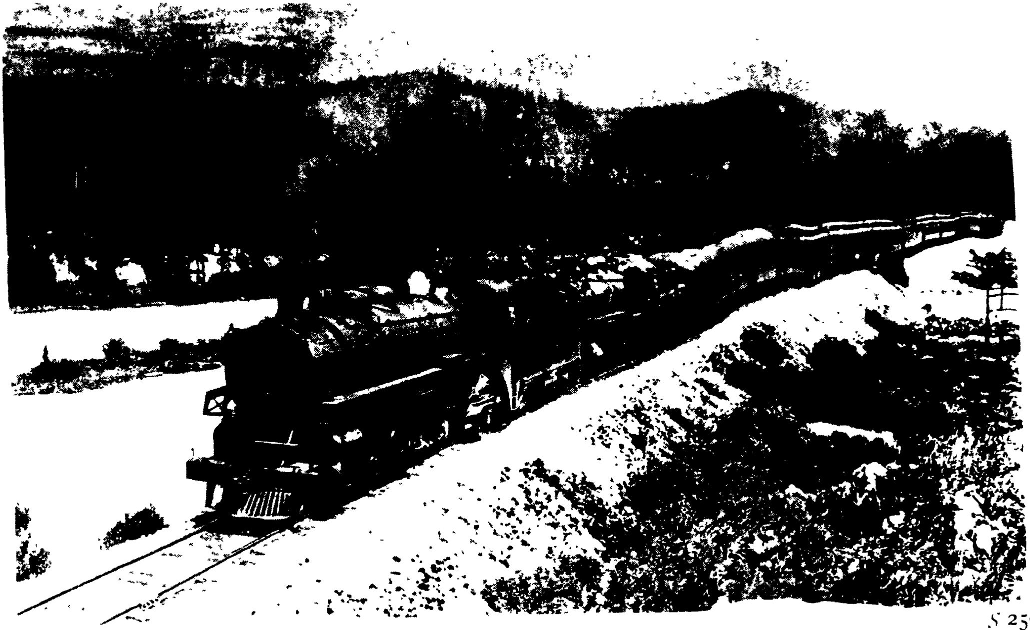
stopped, and the total travelling time of 67 hours worked out at an overall average speed of 43½ m.p.h. In a country of such vast extent as Canada, transport of coal is a costly business and on this account train services on many of the remote branches are in many cases restricted to one train a day or even one on certain days in the week only. The Canadian National authorities hope, by some such means as this, to provide the additional services which are urgently needed, but as yet have been economically impossible. Not only do cars of this type provide speedy and comfortable travel at low operating cost, but in the forest areas of Canada they have the valuable advantage of doing away with the risk of forest fires caused by sparks from the chimneys of steam locomotives. The Canadian Pacific Railway has also in use some gasoline-driven rail motor-cars for branch services.

This chapter would not be complete without reference to the cross-country train services which cover the country in every direction. To a large extent these may, no doubt, be regarded as express trains, whose description rightly belongs to the previous chapter, but from the fact that subsidiary main lines and branches are made use of, in large degree, by these services, it is not unfair to include their consideration in that of the branch lines. The routing of certain of these trains is singular indeed. For example, the through L.N.E. and G.W. express between Newcastle-on-Tyne and Swansea, after travelling down through York, Sheffield, Nottingham and Leicester to Banbury, branches westwards at King's Sutton on to a little-used single line through Chipping Norton and Bourton-on-the-Water in order to strike across country to Cheltenham, where through main line running can be resumed to Gloucester, Newport and Cardiff. Then, from Cardiff, in order that a through service may be given to the port of Barry, the



Pl. 129 *S* 258

The "Union Limited" Express leaving Johannesburg for Capetown, South African Railways (p. 55).



S 250

Pl. 130.

The "Trans-Canada Limited" of the Canadian Pacific Railway climbing through the Rockies. Double-Headed (p. 249).

train proceeds by that circuitous route to Bridgend, before resuming main line running on to Swansea. Over both the two by-ways mentioned, this and its complementary express in the opposite direction are the only two fast trains ever seen. Another joint L.N.E. and G.W. train, running between Newcastle-on-Tyne and Southampton, pursues parts of its journey—in one direction only, strangely enough—over the quiet stretch of the single line branch from Didcot through Newbury to Winchester, beyond which it runs on to the Southern main line for the remainder of its south-bound trip. Many other curious routes are followed by trains of this character.

The development of cross-country travel in this country owes much to the late Great Central Railway, which shortly after the opening of its London Extension in 1899, constructed a short spur line from Woodford Junction to Banbury, on the Great Western main line to the North. By the use of the metals of the Swinton and Knottingley Joint Line, north of Sheffield, a highway was thus opened in 1902 from the north-east coast of England to the south and south-west, through the important towns of Sheffield, Leicester and Nottingham. Over this route are run the through trains between Newcastle and Swansea and Newcastle and Southampton (with a through coach in the latter case to and from Glasgow), as well as the through service between Newcastle and Bournemouth. An innovation since the grouping of the railways has been a through coach service between Aberdeen and Penzance—a journey of 22 hours south-bound and 20½ hours in the north-bound direction—as well as between Glasgow and Torquay. Existing trains are used north of York and west of Swindon a special connecting express carrying the through coaches between York and Swindon. In such cases as these it is not expected, of course, that there will be many—even if any—passengers

booking tickets over the whole course of the through coach run. A through service such as that from Aberdeen to Penzance has many other uses; it affords through communication, for example, from Aberdeen and Dundee to Sheffield and Nottingham, or from the last-mentioned towns, on the other hand, to Exeter, Plymouth and Penzance.

A large number of the through services from north to south are arranged to give through communication between the north and Midlands and the popular resorts of the south coast. Through services concentrate on Bournemouth, in particular, from Birkenhead, Liverpool, Manchester, Leeds, Newcastle, and all the important intermediate cities and towns; Brighton and Eastbourne are served directly from Liverpool and Manchester, Birmingham and South Wales; Folkestone, Dover, Deal, Ramsgate and Margate also have their share of these through communications. Some of the through services run, as we have already seen, over slow and circuitous routes, with the result that it is often quicker to travel *via* London, and to cross the Metropolis by road or tube from one terminus to another. But for through travel with a minimum of expense and trouble, especially in the case of families with luggage, the through cross-country train is a valuable feature of our train services, and in any case the value of the facilities that it affords intermediately, as well as the advantage to the railway of through carriage of merchandise over considerable distances without transhipment, are alone enough to justify the running of these services. Comfortable corridor stock is used, with restaurant car accommodation on practically all the important cross-country trains; in fact, it is now possible to travel by restaurant car train over the whole of Great Britain, from Penzance in the west to Wick in the north of Scotland, so that the British railway passenger need never lack the creature comforts of travel.

A word may be said, in concluding this chapter, as to the road powers exercised by the railways. For many years past certain lines, notably the Great Western and the pre-grouping Great Eastern and Great North of Scotland Railways, have had Parliamentary sanction for the running of road services, of which the Great Western, in particular, has made extensive use, as " feeders " to both main lines and branches, some of the latter, indeed—like the Halesowen branch—having been closed to passenger traffic, and motor-buses substituted. Now that unrestricted road powers have been granted to the railways as a whole, we are likely to see a considerable extension of railway-operated road traffic, both passenger and freight. The Great Western Railway, for example, has entered into an agreement with the National Omnibus Company, whereby the extensive road services of the latter in the West of England are to be operated jointly by both, a new company having been formed for the purpose. Round Sheffield the L.M.S. and L.N.E. Companies have jointly taken over from the Sheffield Corporation road services over a wide area. It is likely, too, that touring road services will be run through scenic parts of the country, similar to those which have been popularised to so remarkable an extent in France by the enterprise of the P.L.M. Railway. Motors of the " Routes des Alpes " and the " Routes du Jura " now cover the whole of the mountainous districts of the east of France with a network of passenger services, run by private companies in conjunction with the P.L.M., and clearly show how road powers, wisely exercised by the railways, can be of great benefit, both to the public and the companies themselves. This extension of railway activity may, indeed, do much to stem the tide of diminishing receipts.

CHAPTER XIV

Suburban and Electric Services

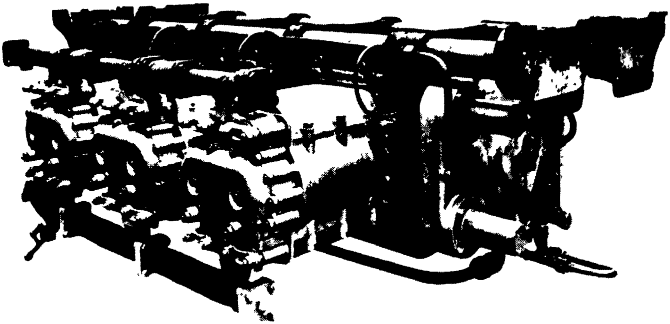
We now come to the suburban train services, which are, generally speaking, the most intensive of all those handled by the railway. The suburban traffic problem is that of handling a maximum amount of passengers in a minimum of time. It is further complicated by the " peak " nature of the traffic. Services connecting residential suburban areas with the business centres of cities have to bring the bulk of the residents to their work between the hours of seven and ten in the morning, and then to return them homewards between about 4·30 and 7·30 in the evening. At these periods of the day there occur, therefore, the " peaks " of the train-loading, when the train service must be expanded to the very maximum, in many cases, that can be run over the lines, in order to provide the vastly increased seating accommodation that is necessary. The intensive flow of trains is not confined, of course, to the direction in which the traffic is flowing, either in the morning or the evening ; in the opposite direction there must be run a corresponding number of empty or partially empty trains in order to keep the terminals supplied with adequate stock for the full workings.

Before we turn to the electric services, it is well to review what has been achieved with steam traction in the matter of passenger handling ; on certain suburban routes, indeed, where electrification has been eminently desirable, but hitherto impossible on account of capital cost, the possi-

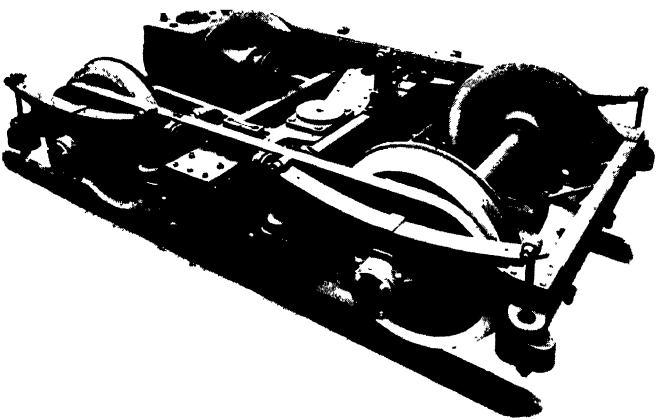
Pl. 131.

S 262.

Driving Compartment of Sentinel-Cammell Steam Rail-Car. Showing Vertical Boiler in



Six-Cylinder " Block.



Driving Bogie.

Pl. 132.

Sentinel-Cammell Six-Cylinder Steam Rail-Car (p. 256).

bilities of steam have been exploited in a remarkable degree. Suburban rolling stock first requires consideration. Maximum seating accommodation in minimum space is a *sine quâ non*, and is arrived at in various ways. In the first place, reduction is effected in the length of the trains by assembling them into uniform sets of vehicles, and "close-coupling." Ordinary side-buffers are replaced by very short buffers, and the coupling between coaches takes the form of a single link, so that the distance between them is reduced to a minimum. Compartments are rather narrower between the seats than those of main line coaches, reducing the amount of "leg room"; the reduction in comfort is negligible on journeys of such short duration as these, but the advantage from the railway point of view is that of introducing an additional compartment within the length of the average coach, and so of curtailing the weight of rolling stock in proportion to the seating accommodation that it affords.

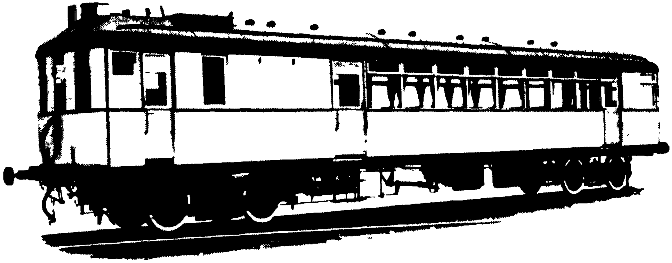
In addition to this the suburban coaches are made of the maximum possible width permitted by the loading gauge, in order to seat as many passengers abreast as possible. It was the old Great Eastern Railway, with the biggest suburban problem of any British railway, which in 1899 introduced the "six-a-side" suburban coach, and so successful were the results obtained with this type of vehicle that not only were many more six-a-side trains built, but the earlier five-a-side suburban coaches were, by the interesting surgical expedient of cutting them in half lengthways and inserting a narrow strip down the centre, converted to hold six passengers a-side in the second and third-class compartments. The standard Great Eastern suburban train of that period, consisting of fifteen four-wheeled coaches, provided seating for 828 passengers.

Since then the London and North Eastern Railway,

train of this weight, offered no small problem in design, but every difficulty was surmounted, and in 1903 there emerged from Stratford Works the remarkable locomotive which was nicknamed the "Decapod" (Plate 137).

This monster 80-ton machine was of the 0–10–0 type, with 4 ft. 6 in. driving wheels, a 5 ft. 2 in. dia. boiler carrying a working pressure of 200 lb. per sq. in., and three cylinders of 18½ in. diameter and 24 in. stroke. A special plant was laid down near Chadwell Heath to test the accelerative powers of the locomotive, and it proved itself more than equal to the test demanded, attaining the necessary acceleration with an eighteen-coach train of 335 tons gross weight. Thus the Great Eastern Railway demonstrated that they could, if and when the occasion required, produce steam locomotives giving all the accelerative advantages of electric traction, and could, therefore, reasonably look forward to carrying the increasing traffic foreshadowed by the electric line; as a result the Bill was defeated. But the "Decapod" was before its time, and the cost of strengthening the underline bridgework sufficiently to carry engines of such weight was not considered warrantable; consequently the "Decapod" was converted to a 0–8–0 tender freight locomotive of considerably lighter weight, and soon afterwards found its way to the scrap-heap. But as a political move the engine fully justified its existence and its cost.

It was the same company—the Great Eastern Railway—which in 1920 put into operation what has rightly been described as the "last word in steam-operated suburban train services." The routes chosen for this intensive steam train working were the suburban lines from Liverpool Street terminus to Walthamstow and Chingford and to Enfield Town, with the branch from Seven Sisters to Palace Gates. An immense amount of preliminary work was undertaken, in order to see where and how the working of the



Exterior View.
Engine and boiler to left: passenger and luggage compartments to right.

S 206

Pl. 133.

Interior of Passenger Compartment.

Sentinel-Cammell Six-Cylinder Geared Steam Rail-Car, L.N.E.R. (p. 256).

By courtesy] C. N. Rlys

Diesel-Electric Articulated Coaches, Canadian National Railway (p. 257).

By courtesy] [L.M.S.

Pl. 134. S 267

Diesel-Electric Train, London, Midland & Scottish Railway (p. 257).

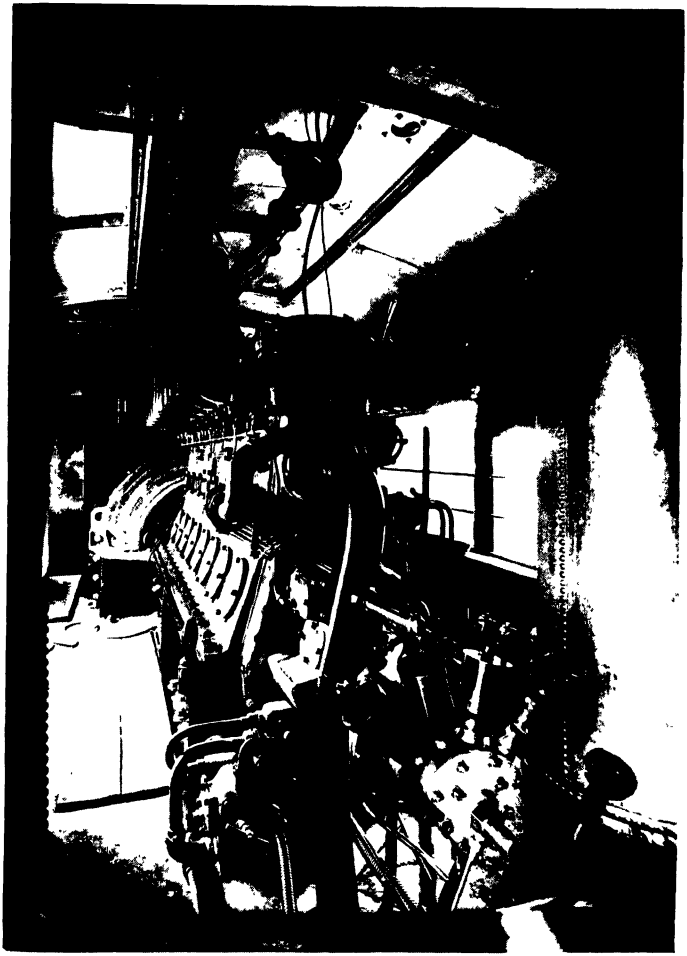
trains could be expedited, if only by a few seconds; alterations were made to track where required and the signalling was modified and improved in such a way as to allow of trains following one another very closely; water-cranes and other minor working accessories were shifted as necessary, in order to reduce the time needed by the engines at the terminals. As a result of the fast and frequent train service thus introduced, the traffic over these sections has been greatly increased, much of it having been won from the roads, and at a cost which was but a fraction of that entailed by electrification.

At the busiest morning and evening "peak" periods of working, steam-hauled trains follow one another at the rate of twenty-four to the hour over the same metals, which these services occupy exclusively for the first 1¼ miles of the journey between Liverpool Street and Bethnal Green Junction; from there to Hackney Downs Junction, where the Enfield and Chingford lines bifurcate, four tracks are available, which enable the expresses to overhaul the stopping trains. Twenty-four of the articulated trains to the hour represent nearly 21,000 passenger seats passing over the same track per hour—probably a record for the whole world in the matter of passenger handling. The whole of the time-table is most ingeniously arranged; during the "rush" hours, of the twelve Chingford line trains, one in every ten minutes is express to St. James St., Walthamstow, and the other six make certain intermediate calls; similarly the Enfield service is arranged with a proportion of express trains, at systematic intervals, and intermediate trains making certain sequences of stops, in such a way that every intermediate station gets a service at even time intervals, the number per hour varying with the station's relative importance.

All through the middle of day the trains are halved, their

adequate seating is also available, generally speaking, for the whole of the journeys during the slack hours. It is only at the times of greatest congestion, and, for the most part, in the central districts of London, that there is extensive "strap-hanging"—that is, a large number of standing passengers maintaining their stability by hanging on to the straps specially provided—and this is characteristic, not only of London suburban services, but of those in all the great cities of the world.

Thus it is that the general design of tube passenger coach (Plate 138) has developed into an open car, with seats arranged longitudinally near the exits, to provide greater standing room in those parts of the car at which entrance and exit are the most quickly effected, and transverse seating in the middle of the cars, between the exits. No longer are exit doors confined to the extreme ends, but all the modern cars are arranged with at least two sets of middle doors, opened and closed by the car conductors from the end of the car with the aid of pneumatic power. In this way the entrance and exit of passengers is facilitated to the maximum degree, and the stopping time at the majority of intermediate stations is cut down to 15 seconds or less, which means a corresponding acceleration of total journey time. Records which have been taken on special occasions—such as the annual Air Pageant at Hendon Aerodrome, which brings fully 40,000 people to Colindale Station in a very short space of time—show that the latest trains, in which each coach has three sets of pneumatically-operated side-doors, can disgorge themselves of 750 passengers in the brief space of 20 seconds. It is of interest to note here that the safety of passengers in these trains with automatically-worked side-doors is ensured by the fact that the driver is unable to start the train until all the side-doors are closed.



By courtesy] [*L.M.S.*

Pl. 135. *S* 270.

Engine-Room of Diesel-Electric Train (p. 257).

Diesel engines in foreground; direct-coupled dynamo in background.

Photo by] [F. R. Hebron.

Pl. 136. S 271.

Articulated Suburban Train, London and North Eastern Railway (p. 264).

Consisting of two quadruple sets of coaches, hauled by 0-6-2 suburban tank locomotive.

In the earlier conversions of some of the surface steam-worked lines to electrical operation the same principles of coach design were followed. For the South London section of the London, Brighton and South Coast, for example, special coaches were built with transverse seats and side corridors, affording internal passage from one end of each car to the other. Open coaches, too, were used for all the London and North Western electrified services, with end exits only. It has since been realized, however, that coaches of this type provide too little seating accommodation for suburban journeys, some of which are of considerable length—such, for instance, as the 21 miles from Broad Street to Watford—and in all the latest coach sets for suburban, as opposed to tube, services the compartment system is being reverted to. On the Southern Railway, apart from the early experiment on the South London line, just mentioned, nothing but compartment stock has been employed, and a large number of the previously existing suburban coaches have been modernized and suitably equipped for electric working, thereby saving the railway concerned the heavy expense which would have been entailed by using new stock exclusively on its extensive electric system.

If the maximum value is to be derived from suburban electrification, track and signalling arrangements must receive special attention, in order that safe working may be maintained with a minimum time interval between trains. The British frequency record, which is also, probably, a world's record, is the 42 trains per hour, over the same line of metals, reached by the Metropolitan District service during the rush hours between Mansion House and South Kensington; this compares with the 24 trains per hour of the L.N.E.R. "intensive" Walthamstow and Enfield suburban service, which, as previously mentioned, is

probably a world's record for steam operation. But such a frequency as 42 trains per hour could not be attained apart from automatic signalling, power operation of switches at junctions, and "flying" or "burrowing" connections (Fig. 19) to and from branch lines, to avoid the necessity for trains crossing each other's tracks "on the flat." Time is obviously the essence of such traffic problems as these, and the human must thus give way to the mechanical and the automatic.

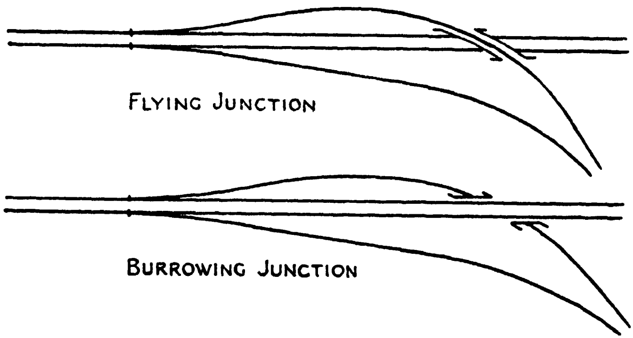


FIG. 19.—"Flying" and "Burrowing" Connections.

Some of the London tube junctions are of extraordinary complexity. Most noted of them, probably, are the junctions between the Charing Cross and the City tubes at Mornington Crescent. The original Charing Cross, Euston and Hampstead tube—now extended southwards to Morden and northwards to Edgware—bifurcated at Mornington Crescent, one section proceeding to Golder's Green and the other to Highgate. The usual twin tunnels therefore branched into four, the junction being so arranged that the down Highgate trains passed over the up Hampstead trains, and no train therefore fouled the path of another. In

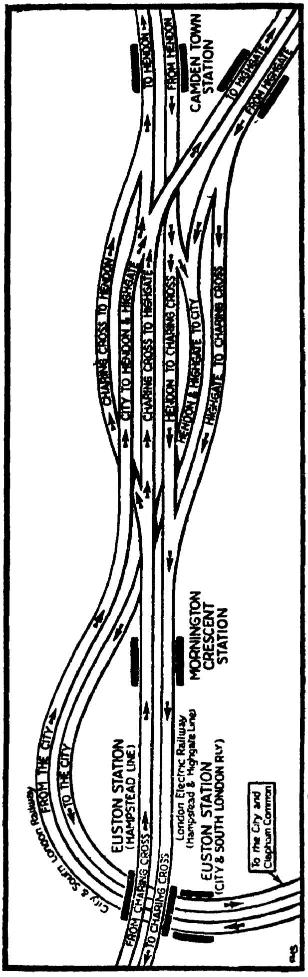


FIG. 20.—Diagram of Camden Town Junctions. London Electric Railways.

bringing in the twin tunnels of the City line, it had similarly to be arranged that there should be no fouling movements; that no down and up trains should cross each other's tracks; that a down City to Highgate train should not pass over any part of the same metals as a down Charing Cross to Hampstead train, or *vice versa*; and, in the same way, that the up services should be entirely independent of each other.

How this has been done only the diagram which forms Fig. 20 could make plain. The result is that two services of equal frequency converge from the south on these junctions; that each service splits into two equal parts, for Hampstead and Highgate respectively; and that the four halves dovetail into two services of the original frequency, along the two branches; further, that the same converging services from the two branches, travelling southwards, split up at Camden Town and re-

assemble at Mornington Crescent. No less than 1,450 trains pass through these junctions during the course of a day—actually within the compass of 20 hours—no one of which crosses the track of another, or is, indeed, so much as visible to another; all the junctions and signals are, of course, power-operated, by a couple of signalmen in a cabin from which only one-quarter of the trains passing are ever seen; but the position of every train within the control of the signal-cabin is clearly shown on an electric track-plan above the lever frame.

When the Morden extension was made, the Charing Cross line was extended to join the City line at Kennington, where another complicated junction has been laid out, with four tunnels converging to two, and, in addition, a loop tunnel at the south end of the station to enable trains terminating at Kennington to run straight round from the south-bound to the north-bound side of the station without the trouble and time (in its turn causing temporary blockage of the line concerned) involved in reversal. It is of interest to note that these labyrinthine junctions at both Mornington Crescent and Kennington were laid in without any interruption of the tube services operating over the lines concerned.

The details of the signalling to which reference has been made are discussed further in Chapter XVIII, but some of the aids to expeditious working on the tube lines are worthy of remark. The tracks out of each station are arranged on a rapidly falling gradient, in order to encourage rapid acceleration, and into each station, similarly, the lines are on rising grades, in order to reduce to a minimum the loss of energy involved in braking. Headway clocks have been installed at the tunnel-mouths of many stations, so that the driver of a train may see exactly how far ahead of him the next train is travelling, and, if the distance be but short, he is able, by running his motors at reduced

power, to work his train at a lower speed and so to economize in current. Over each of the tube lines, at certain selected points, the trains automatically record their passage, and the passing of all trains is repeated automatically on large dials

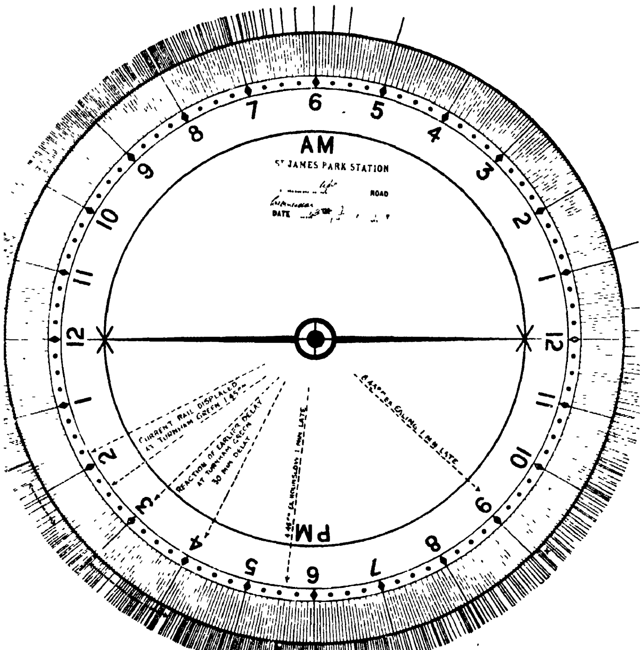


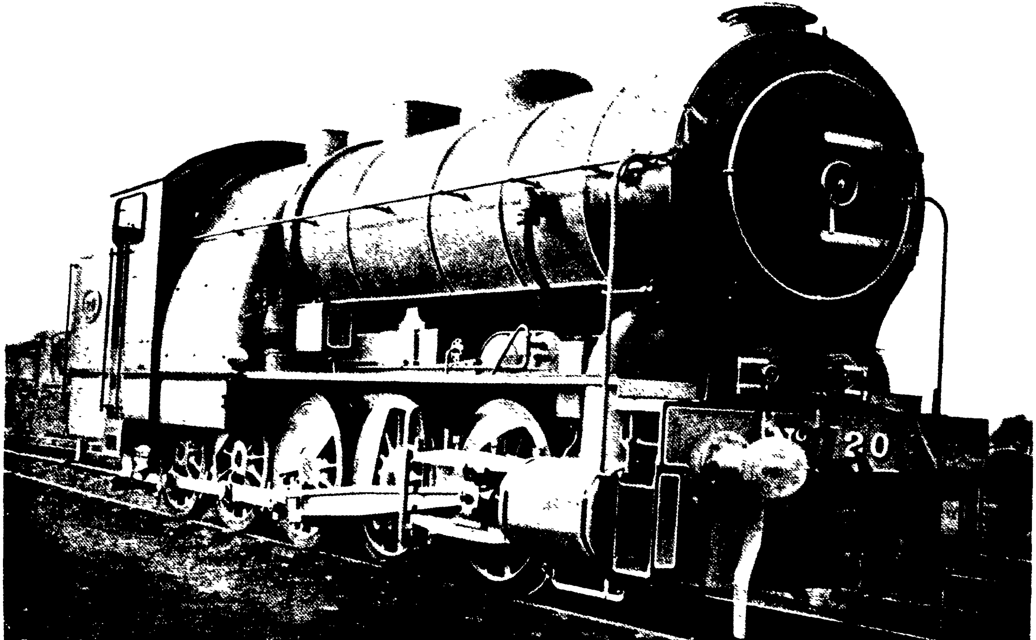
FIG. 21.—Automatically-recorded Train Service Diagram, London Electric Railways. Taken on the up road at St. James' Park Station, on June 13th, 1928. The reasons for irregularity in the train frequency are explained in the centre of the dial. These records may now be seen by the public daily in the booking-hall at Piccadilly Circus Station.

(Fig. 21), each covering the complete twenty-four hours, in the Central Control Office at Leicester Square, and at certain other strategic points. The markings made by the recording

pen should be at equal intervals, and any undue gap between adjacent markings indicates to the Controller immediately that there is some derangement of that particular service. By telephone he is in direct communication with every station, signal-cabin and depot on each of the lines under his control, and is thus in a position to enquire directly as to the cause of delay, and, if called for, to give the necessary instructions as to its rectification.

It is not too much to claim that the London Underground lines represent the most complete and elaborate system of railway passenger handling that the world has ever yet seen. Every device imaginable for the expedition of working has been pressed into service. Tickets are issued and change is given from automatic machines ; lifts are in course of supersession constantly by the never-stopping escalators, or moving stairways (Plate 142) ; on the platforms the destination of the trains is indicated by platform indicators, automatically operated by the " train describers" (Plate 141) in the junction signal cabins, which ingeniously " store up " their information concerning quite a lengthy sequence of trains ; train doors are opened and closed, as we have seen, by automatic means ; station-to-station journeys are expedited by the way in which the track is graded ; intervals between trains are closed up to a minimum by automatic signalling ; overall journey times are speeded-up by making alternate trains miss different sets of the less important stations, each of which thus enjoys one-half the service provided for the more important stations ; and other devices innumerable might be mentioned. In order to prevent the delay which might be occasioned by taking one single train out of service, minor defects are often cured by a special travelling staff of engineers without any stoppage of the train concerned.

Some of the figures concerning London Underground



Pl. 137. *T* 276

The "Decapod" (0-10-0) Suburban Tank Locomotive, Great Eastern Railway, 1903 (p. 266).

Pl. 138. *T* 277.

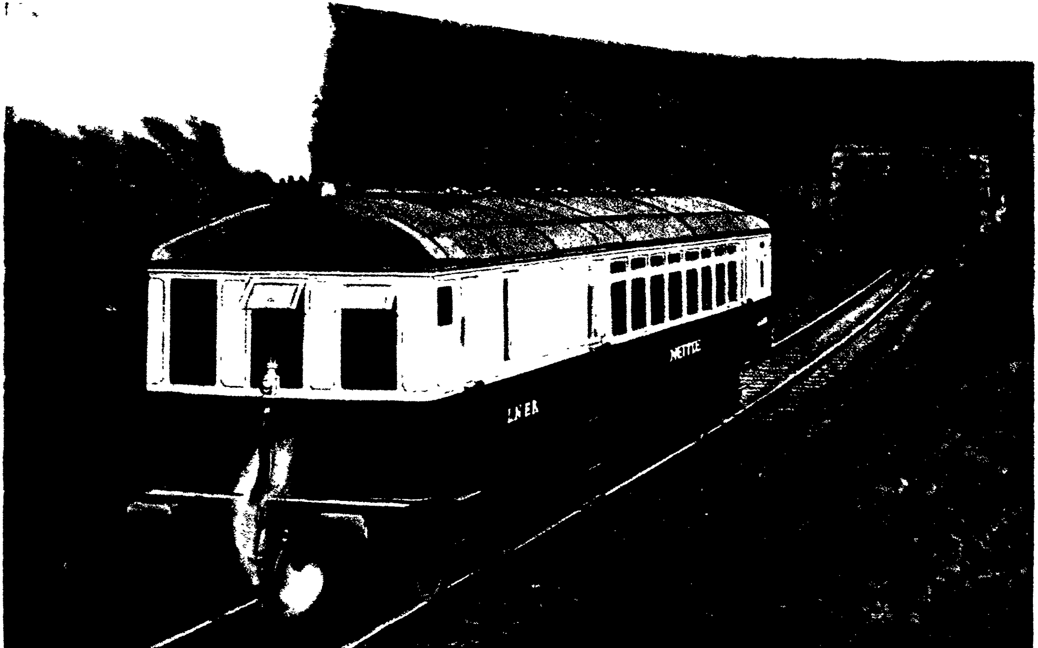
Pneumatically-operated side-doors, London Underground Tube Coach
(p. 270).

passenger operation are almost unbelievably big. The number of passengers conveyed annually is now all but 350,000,000, and the number of trains operated annually is more than 2,300,000. Out of the total route mileage of the system, which amounts to 78¾ miles, 206 single track miles are equipped with entirely automatic, semi-automatic or power signalling, comprising 868 automatic and 971 semi-automatic signals, together with 85 fog repeating signals, and 1,091 automatic train-stops. Forty-seven of the signal cabins are equipped with power signal frames (Plate 141) with illuminated diagrams, showing the exact position of every train in the whole of the area controlled by each box. Busiest of all the stations is Charing Cross, which, with its three different levels of tracks, deals with 195 trains per hour at its heaviest periods and 2,836 in all daily. The busiest of the tube junctions, as we have seen, is Camden Town, handling 90 trains per hour, or one every 40 seconds, during the rush hours.

The electrically-operated traffic of some of the surface lines is also extremely heavy, and particularly that of the Southern Railway out of Waterloo. Time-tables of electrical services are almost always arranged on systematic lines, with trains to each branch at definite intervals, so that the public may become familiarized with the electric service at their own particular station without reference to time-tables. Most of the Southern four-track main lines out of London are arranged with the fast lines in the centre, and the slow, or " relief " lines on either side, the various branches being arranged to leave by means of flying or burrowing junctions, so that the fast lines are in no case fouled by the crossing on the level of the electric services. Where it has not been possible so to remodel the lay-out, as at the convergence of the Cannon Street and Charing Cross lines near London Bridge, considerable expedition of traffic

handling has taken place as the result of the institution of "parallel working," which has reduced the train fouling movements to a minimum.

The most costly of all the track alterations to surface lines, preparatory to the conversion from steam to electrical operation, has probably been that between Chalk Farm and Primrose Hill Tunnels, on the L.M.S. main line, a little over a mile out of Euston terminus. Fast lines, slow lines and electric lines reach the south end of Primrose Hill Tunnels parallel to each other, looking from right to left as one faces London; inwards from Chalk Farm, ½-mile further on, these have re-sorted themselves, again looking from right to left, into empty carriage lines, down fast line, down and up electric lines (making for the centre platforms at Euston) and up fast line; also the down and up lines to Broad Street. Here again, by the most admirable planning, direct communication has been given from practically every one pair of lines to every other, without any fouling of up and down trains by crossing on the level. The bulk of this amazing lay-out is underground, and only a few portions of it are actually visible to the passing traveller. So our railways progress in the handling of their vast suburban traffics; and if the progress is not as rapid as the traveller sometimes desires, he may take it as certain that the delay arises rather from lack of means than from lack of desire to improve the speed and comfort of his travel.



Pl. 139. Sentinel-Cammell Steam Rail-Car "Nettle." L.N.E.R. (p. 255). T 278.

Pl. 140. *T* 279.

Edgware Tube Terminus, Underground Electric Rlys. of London (p. 197).

CHAPTER XV

Freight Trains

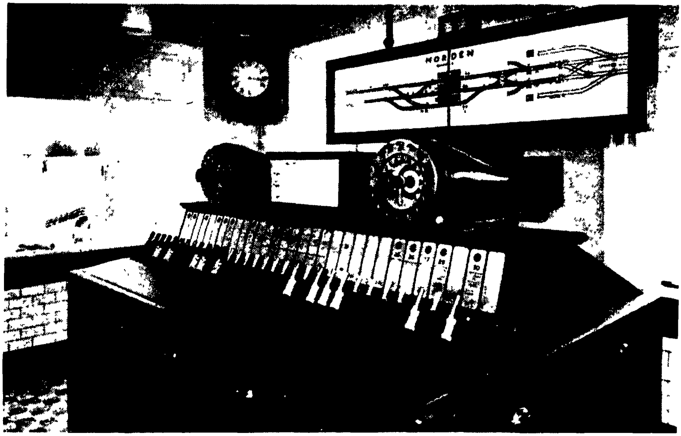
FREIGHT traffic is the backbone of railway revenue. There is no happening which has so adverse an effect on receipts as a serious trade dispute, such as a coal strike; even though passenger traffic may be maintained at a fairly normal level during such a period, the losses of revenue arising out of the cessation of coal haulage and the reduction in haulage of other merchandise are sufficient, generally, to lower the gross receipts far below the gross expenditure of the railways. At the same time it would be idle to contend that the operation of freight traffic in this country is as profitable as it might be. Statistics prove that the average movement of the British wagon per day amounts only to 10½ miles, and that its wheels are turning for but 1¼ hours of the twenty-four. Taking averages all over the country, the mean length of a British freight train is only 35 four-wheeled wagons, and the mean speed of freight trains, all stops included, only 8½ miles per hour. Further, it is calculated that the actual loads carried amount to but 51 per cent. of the wagon capacity employed to carry them, and that an increase in wagon loads of no more than one ton per wagon would be equivalent to the addition of a quarter-of-a-million wagons to the rolling stock of British railways.

A great many causes have combined to produce these results. In the first place, the wagons of this country are, in general, of smaller capacity in proportion to gauge than

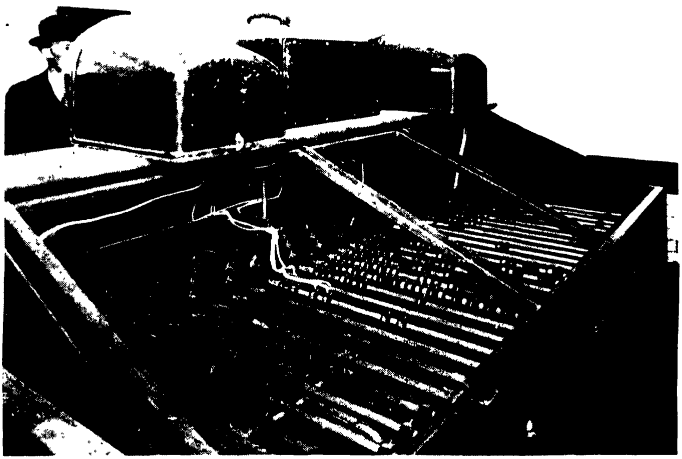
line occupancy of a freight train, and especially the length of sidings required for its stowage, while the reduction in weight bears on the locomotive power, and in particular the coal consumption, needed to keep it in motion. So vitally is this fact realized by the Great Western Railway that a special rebate in carriage charges is granted by that company to colliery owners and coal merchants who are prepared to use the new all-steel Great Western 20-ton coal wagons in place of the smaller wagons of 12 tons and 10 tons' capacity otherwise used.

Twenty tons by no means expresses the maximum wagon capacity which it is possible to use. In addition to special bogie wagons of flat and well types, provided for the carriage of very bulky loads, most of the British railways have a few bogie wagons, of about 40 tons' capacity, devoted chiefly to the carriage of coal for their locomotives. For working of heavy brick traffic from the large brickfields in the Peterborough district, the London and North Eastern Railway has in use some fine bogie brick wagons, each of which is of 50 tons' capacity; the empty weight of these is 17 tons per wagon, so that the tare only reaches 34 per cent. of the load conveyed. This is a considerable advance on the 60 per cent. tare to load of the old 10-ton wagons.

But we are still far behind the Americans in this matter. The United States and Canada, with their far-spreading territories, certainly have the advantage of us in regard to length of haul, and, as we have seen, have also developed the habit of the large bulk consignment of minerals and merchandise rather than our small consignments. The whole of their wagons are of bogie types (Plate 143), both open wagons and closed, or "box," wagons, and in some cases very high capacities are reached. The latest Canadian grain wagons of the Canadian Pacific Railway, for example,



Operating side of frame, showing miniature levers, signal repeaters above, and train-describers (circular) on top of frame, and illuminated diagram behind (p. 276).



Pl 141. *T* 282.

Back view of frame, showing electric locking.

All-Electric Signal Frame, Morden, London Electric Rlys.

Pl. 142. *T* 283

Triple Escalator, Tottenham Court Road Station, Underground Electric Railways of London (pp. 276, 317).

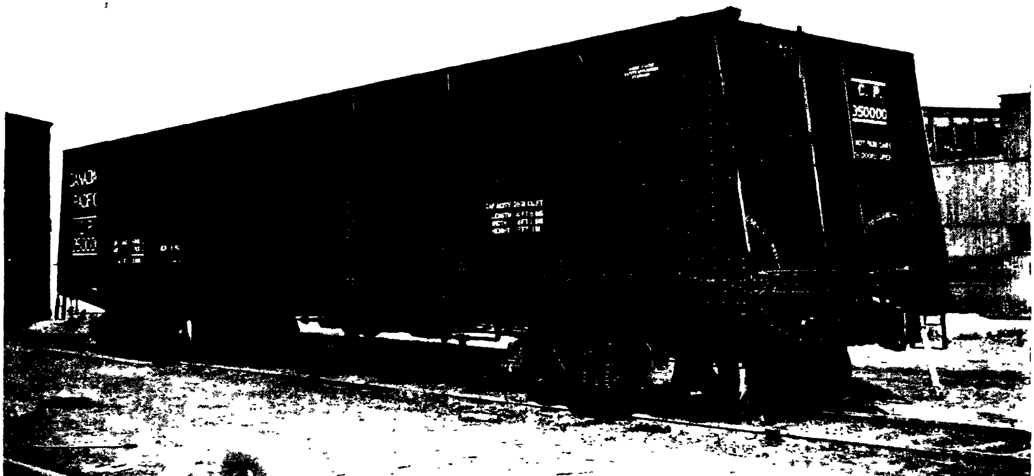
have a capacity of 89 English tons each. On the Virginian Railways of the U.S.A., with their heavy traffic in coal from the mines for shipment at Sewall's Point, the standard all-steel coal wagon is now a monster vehicle supported on six-wheeled bogies and carrying 107 English tons. The fact that these cars are tipped bodily at the seaward end of the journey, instead of emptied through hoppers or side doors, enables so light a steel construction to be used that the tare of each wagon is only 35 tons, and 76 per cent. of the full weight of each car therefore represents paying load.

The largest freight train ever assembled in the world was over this route, in 1920, when 111 of these wagons, carrying in all 11,460 tons of coal and making a train whose gross weight was 15,400 tons, and whose length totalled 6,050 ft., were worked by one 2–10–0 + 0–10–2 Mallet compound 400-ton locomotive over the 125 miles from Victoria to Sewall's Point. To carry a corresponding load, 573 British 20-ton wagons would be needed, making a train of over 2 miles in total length. Even on the 3 ft. 6 in. gauge of South Africa the largest 12-wheeled bogie wagons (Plate 26) have a capacity of 67 tons apiece. Four-wheeled wagons are favoured on the Continent, but of considerably greater length and capacity than those generally employed here.

There are other matters connected with the movement of freight in which Great Britain is somewhat backward. The " loose " coupling of three links is in practically universal use, to which the most damaging objection that can be advanced is the risk that it occasions to shunters in coupling up and uncoupling the wagons at the marshalling yards. In view of the limited power of many of our freight engines, however, the loose coupling has the advantage of enabling a driver to stop his train with all the couplings slack,

and then the more readily to start away again, the load coming on to the engine by degrees as the couplings tighten throughout the length of the train. In America automatic couplings alone are used, whereby two wagons couple themselves together automatically, on being brought together, if the couplings are in the right position to engage; this type of coupler has already been mentioned in connection with passenger rolling stock, having for many years past been applied to the corridor coaches of the London and North Eastern Railway. Not only is risk of injury to the men avoided, to a very large extent, by the use of automatic couplers, but time is economized in the work of coupling up in marshalling yards, and the greater strength of the couplings themselves is a valuable safeguard against "breakaways," resulting from broken couplings. One has only to listen to the starting of a long loose-coupled freight train in this country to realize the strains to which the couplings are subjected as one by one they are violently pulled taut. It is the greater difficulty of starting the rigidly-coupled American freight train which has led to the widespread introduction in that country of the "booster," described in Chapter VII, whereby additional power is developed by the locomotive with a small two-cylinder auxiliary at starting and on heavy grades.

Another matter having an important bearing on freight operation is that of brake power, and here again Great Britain has been backward in development. On any ordinary freight train in this country all the wagons are furnished with hand-brakes, but there is no means of applying these while the train is in motion, and the only brake power available, when the train is moving, is the power brake on engine and tender—Westinghouse, automatic vacuum, or steam—and the screw hand-brake on the guard's brake-van at the rear. The latter is specially

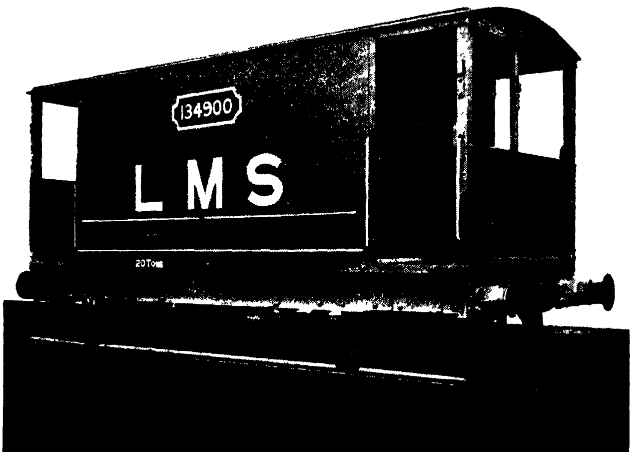


Pl. 143. *T* 284

Steel-framed high-capacity wagon, Canadian Pacific Railway (p. 282).

Capacity: 2641 cub. ft.: 100 American "short" tons or 89 British tons.

10-ton Wagon (p. 281).



By courtesy] [*L.M.S*

Pl. 144. *T* 285

20-ton Brake (p. 285).

weighted in order that its brake-power may be more effective, and is often carried on three axles (and occasionally four) for the same purpose ; the average brake-van used for freight purposes in this country is of about 20 tons' weight (Plate 144). But with all such precautions, it will be understood readily that with an average freight train of, say, 60 coal wagons, weighing in all, perhaps, 1,100 tons, the brake-power afforded by an engine and tender of 110 to 120 tons and a brake-van of 20 tons is but modest in its extent and slow in its application. For this reason the British freight train must either be run, for safe operation, at low speeds, or it must be limited in weight, if higher speeds are to be allowed with safety, and the general tendency of this country has hitherto been in the latter direction. The average formation of a British freight train, as we have already seen, does not exceed 35 small capacity wagons, and this, in its turn, will explain why such large numbers of freight engines of the 0–6–0 type still continue to find useful employment in this country ; on the L.M.S. system, indeed, this is now the standard construction (Plate 63) for freight work.

But it must be remembered that, no matter how limited the load, the " overhead " cost of providing engine, fuel, driver, fireman and guard remains unchanged, so that the greater the load per engine, the more economically it is possible to conduct the working. On the other hand, if the line occupation is increased by the working of very heavy freight trains with large engines at necessarily low speeds, congestion is likely to be caused, and loss of another description will occur. Some of our main lines have, however, endeavoured to increase their freight train loads to the maximum reasonably possible with single engine haulage ; on the main lines of the G.W.R. and L.N.E.R., in particular, the 2–8–0 freight engines (Plate 64) are entrusted fre-

quently with trains of between 70 and 80 wagons. The two L.N.E.R. booster-fitted 2–8–2 ("Mikado") engines, uniform in general design with the "Pacific" passenger locomotives, are rostered to take 100-wagon trains (Plate 146) of a gross weight of nearly 2,000 tons, but special paths have to be plotted for these trains in the time-tables, in order that they may be given a clear run between Peterborough and London without the likelihood of having to be shunted anywhere *en route*. This fact demonstrates, in a striking way, that freight locomotive development in this country is limited more by operating conditions than by the physical limitation of the construction gauge.

In North America, for many years past, the compressed air brake has been not only standard, but a compulsory item of wagon equipment. As far back as 1893, the American Government enjoined upon the railways that after the expiry of five years—to give time for the equipment of the stock with brakes—50 per cent. of the vehicles in every freight train must be equipped with power brakes and marshalled next the engine. Shortly afterwards a fresh decision was reached, that after August, 1906, the power brake equipment must extend to 75 per cent. of the vehicles being so equipped, with the result that, as the simplest way out of the difficulty, the American main lines have now fitted the whole of their freight stock with continuous brakes. As a result, not only is there no reasonable limit to the length and weight of the American freight train, but its speed, on the average, is higher than that of its British counterpart. The French Government has recently come to the same decision, that power brakes shall be compulsory on freight trains, and has communicated it to the French railways, giving them a certain length of time in which to carry the decision into effect.

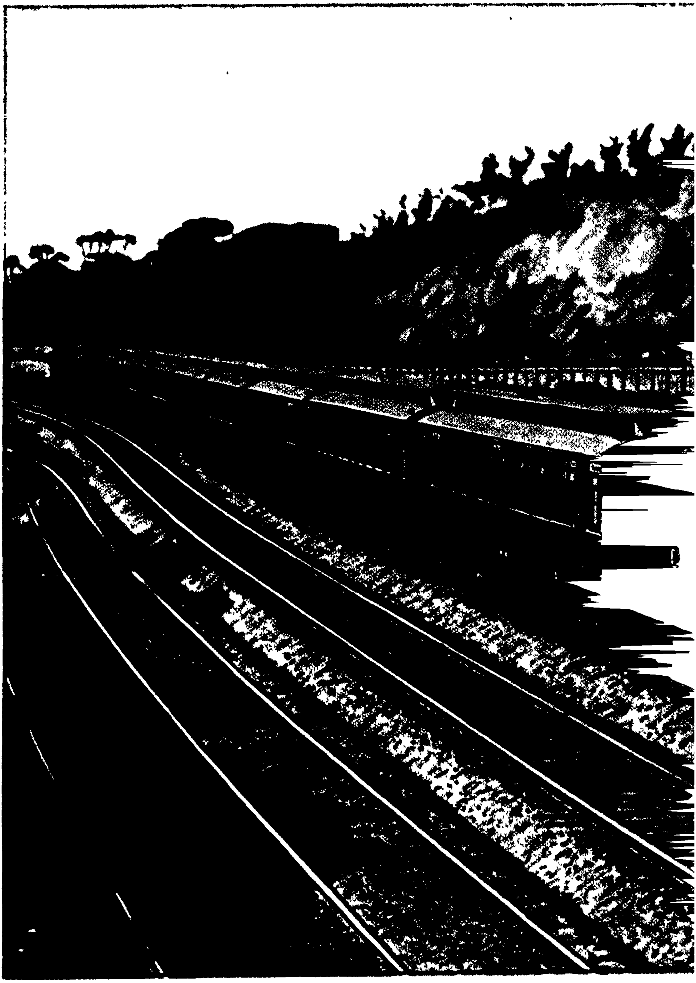
A certain proportion of British wagon stock is fitted with

the automatic vacuum brake and used in the composition of express freight trains, generally devoted to the conveyance of "perishable" traffic—fish, meat, fruit, and foodstuffs, in particular. Many of these trains run under "express passenger" headlights and regulations, and at speeds but little inferior to those of the passenger trains themselves. Several of the L.N.E.R. fast night freight trains from King's Cross Goods Station to the North, for example, are timed to cover the 27 miles from Hitchin to Huntingdon in 32 minutes, at an average speed of over 50 miles an hour, and this with a load of 60 wagons and a brake, which may total up to 1,000 tons. Over the same route two express milk trains, bringing milk for London's millions from the farms of Staffordshire and Derbyshire, run nightly without a stop over the 103 miles from Grantham to Finsbury Park at overall average speeds of 48 m.p.h. Up the West Coast route an express fish train runs every night from Aberdeen to London, earning distinction from the fact that it makes in succession non-stop runs of 141 and 162 miles, from Carlisle to Crewe and from Crewe to Broad Street terminus respectively. Such trains as these must, of course, be composed throughout of vacuum-fitted vehicles. Beyond the wagons which are fitted with the power brake itself, a large number are "piped"—that is to say, provided with through pipes, so that they may be run, if necessary, in continuous-braked trains without interrupting the continuity of the brake communication.

The composition of the British freight train includes, as previously mentioned, a guard's brake at the rear end. As the guard may have to spend considerable periods of time in this at a stretch, the interior is made as comfortable as possible, the equipment comprising in particular a coal-fired stove for warmth in the winter months. On the Continent of Europe it is not customary to employ inde-

pendent guard's brakes, but a certain proportion of the ordinary covered wagons are provided with very small guard's compartments at one end, and in this exiguous space the guard has to bestow himself, usually in the rearmost wagon of the train that is so fitted. The most exciting occupation for a freight train guard that history records fell to the American brakesman of the days prior to the introduction of continuous brakes on American freight wagons; when his train was about to stop or to descend a steep gradient, he had to race madly along the roofs of the box cars in order to screw down sufficient of the car brakes.

An operation of great importance in connection with freight working is that of marshalling the wagons of the trains in their proper order. The slower trains pick up the wagons at the various intermediate stations along the branch and main routes, and convey their loads to the chief traffic centres, where marshalling yards have been laid out. Some of the larger yards are of enormous size, and their tracks, if laid out end to end, would extend for many miles. The tracks are usually arranged in gridiron form, separate gridirons being devoted to reception and to despatch. In order to economize in the engine power required for the actual work of sorting, it is now customary to employ "humps" for this purpose. The track leading to a gridiron is carried on a gradual upward gradient to the summit of an embanked "hump," whence it falls sharply towards the switches giving admission to the sorting sidings. On the arrival of a train for marshalling, a powerful yard engine takes charge, and pushes the whole train slowly over the hump. Just before reaching the summit, each wagon is uncoupled by a shunter, and by the appropriate manipulation of the switches immediately beyond, is directed (Plate 148) to its proper track. The sharp



Pl. 145.

The Inter-State Express, Sc
Hauled by 4

T and U.

lian Rly. 5ft. 3in. Gauge (p 52).
ress locomotive.

descent from the top of the hump causes each wagon to draw rapidly away from the next following, and so allows time for the movement of the switches. In the latest installations, such as those at Feltham, on the Southern Railway, or Wath, on the L.N.E.R. (Plate 148), the switches are power-operated from a cabin situated on the top of the hump, from which a good view of the operations can be obtained.

In the design of the wagons themselves regard is paid, as far as possible, to the type of load which they are intended to carry. Minerals are, to a large extent, conveyed in "hopper" wagons, which are filled from above but discharged from below; for this purpose the sides of the wagon are sloped inwards towards the centre, and suitable bottom doors, operated from outside, allow the load to slide through the floor of the wagon when they are opened. In the work of coaling, wagons are often seized bodily by the coaling plant, and tipped either sideways or endwise; in the latter case the wagon must be provided with end doors. Increasing use is now being made of "container" wagons; that is to say, flat wagons carrying detachable boxes, or containers, which can be lifted bodily off the wagons on to road lorries (Plate 149). This method has the advantage of saving a great deal of handling of the merchandise at the starting point and the destination, at the same time minimising the risk of breakage or damage, but it reduces the wagon capacity in proportion to tare weight.

Much might be written concerning the vast diversity of wagons in use, did space permit. The three main classes are the covered, or "box" wagon; the ordinary open wagon; and the flat wagon (Plate 151). The last-mentioned, when intended for such loads as timber, steel rails, and so on, is provided with "bolsters," on which the load actually

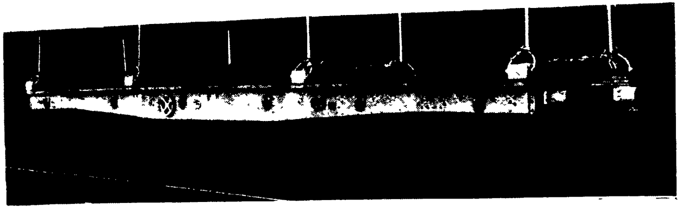
rests, a lengthy load may require two or three of these bolster wagons in succession for its accommodation. Fine bogie bolster wagons (Plate 147) are now in use, however, up to 50 ft. long, one of which alone can carry a load of, say, 60 steel rails 45 ft. long, weighing roughly 40 tons. For loads of large bulk, such as machinery, many of these flat wagons are provided with sunk centres, and are termed "well" wagons (Plate 147); the load is mounted in the well, in order that sufficient clearance may be obtained for its passage under bridges and through tunnels. In the case of loads of exceptional magnitude, such as the rudder of s.s. *Aquitania*, seen in transit in Plate 150, it is occasionally necessary to obtain possession of both up and down roads of a double line of railway, as the clearance round one track would be insufficient; such an operation, of course, demands very careful preparation, and can only be carried out on a Sunday, when normal traffic is reduced.

Box wagons also are most varied in character. For the conveyance of perishable traffic special provision must be made; for this purpose there are refrigerator wagons, keeping the consignment—usually food-stuffs—at a low temperature, or insulated vans, for the purpose of keeping the load at an even temperature. Such freight as bananas, on the other hand, requires steam-heated wagons, as in this case a high temperature is needed. Special stock is provided for the conveyance of live animals, the cattle wagon—a kind of compromise between an open and a closed wagon—being a familiar object in freight train formations. It is furnished with removable partitions, converting it, as desired, into "large," "medium" or "small" accommodation; this is necessary as the cattle must be packed sufficiently closely to prevent the possibility of their being thrown over when the wagon is starting or stopping, or being shunted. For horses considerably more elaborate accom-

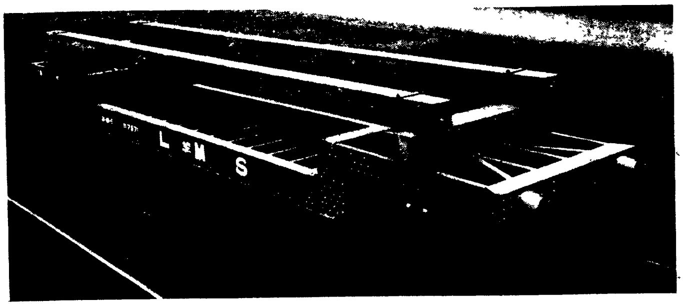
Photo by] [F. R Hebron

Pl. 146. U 290

Booster-fitted "Mikado" Freight Locomotive hauling 100-Wagon Train, L.N.E.R. (p. 286).



Bolster Wagon, for lengthy loads.



Photos by courtesy] [*L.M S.*

Pl. 147 U 291.

Well Wagon, for bulky loads.

modation is provided, although the "horse-box," as it is known, is a passenger rather than a freight vehicle, and is practically always conveyed by passenger train. The same remark applies to the "carriage truck" and the "motor van."

As regards the open wagons, the chief distinction between the different types lies in capacity, and in the method of discharge, whether side door, end door, or hopper. Protection is provided for loads which might suffer damage from weather by means of large tarpaulin sheets, for the use of which an appropriate charge is made. Many of the commodities carried require the use of wagons of special design such as oil wagons, tar wagons, chemical wagons, gunpowder wagons, to name but a few examples. For their own purposes, again, railways employ various special wagons, such as those devoted to the carriage of ballast for the track (Fig. 64), and, yet again, stores vans, which make periodical journeys along each route in order to keep the stations supplied with oil, cotton waste, and other requisites. "Service" wagons are distinguished on the L.N.E.R. by being painted blue. Altogether there are a million and half freight wagons at work in the British Isles alone, and thousands more are built annually in order to replace those withdrawn from service by reason of age. Mass production methods are resorted to in the construction of all the standard types, and in one of the latest plants the whole work of wagon assembly from the raw material of the tree trunk to the finished wagon, with all the metal parts brought together in readiness, is carried through in the brief space of two and a half hours.

Reference has already been made to the use of "container" wagons, whereby transhipment of load from lorry to train and from train to lorry, at the beginning and end respectively of the railway journey, is avoided. A similar

CHAPTER XVI

Time-Tables and Traffic Control

FEW of those who make use of railway time-tables have the remotest conception of the labour involved in their compilation. Some time ago, when certain important railway accelerations were in prospect, a London newspaper gravely wrote as though the time-table makers were sitting down somewhere near the end of May to decide the alterations that they would incorporate in their July time-tables, some four or five weeks ahead. To any of the staff actually engaged in the work of time-table compilation, this would make amusing reading.

Each year the time-tables see two drastic reorganizations; the summer train service proper comes into force early in July, and the winter service is reimposed at the end of September. The first preparations towards any summer train service are probably made during the previous October. Conferences are then held among the officials chiefly concerned as to the working of the trains during the summer service just ended, and notes are made as to the alterations and additions to trains deemed desirable in the next following summer.

During the winter the higher officials will make their decisions as to any radical changes or alterations which are to be brought into force, so that these may be duly incorporated. But even this is not so simple an operation as might appear. It would be idle to set down on paper accelerated times, if there were insufficient engines available

of the requisite power and speed capacity to give effect to them, to mention but one consideration. All such questions as these, therefore, have very seriously to be faced. Generally speaking, however, radical changes—which, when made, involve an enormous amount of work to the staff—are but few, and the train services settle down more or less into "grooves," the alterations necessary being in detail only. But even alterations to one single train can have an influence almost unbelievable in its extent; connecting trains all over the system may, and probably will, be affected by any modification of the schedule of a long-distance express. For a railway time-table is like a piece of mechanism of extraordinary complexity, pieced together with the utmost care, any disturbance of which may have consequences of but little realized seriousness.

Time-table complication is best realized by references to one of the large diagrams on which main line train services are usually plotted. These diagrams (Fig. 22) consist of large sheets of squared paper, on which the stations and sidings of the portion of the route concerned are set out vertically, and the twenty-four hours of the day, each divided into their sixty minutes, appear horizontally. The path of each train then appears as a diagonal line across the diagram; according to its description, whether express passenger, slow passenger, fast freight, heavy mineral, light engine, empty coaches, and so on, a different kind of dotted line is usually employed, for distinctive purposes. The faster the train, so much the steeper is the angle of the line by which it is indicated. Each stop, as well as its duration, is clearly seen by the horizontal break in the line of the train opposite the station concerned. Thus every train, of whatever kind, has its own particular "path," and the times at which additional trains may be dovetailed in, with a minimum of disturbance

to existing services, is readily apparent by reference to the diagram.

But the work on these diagrams forms only a small

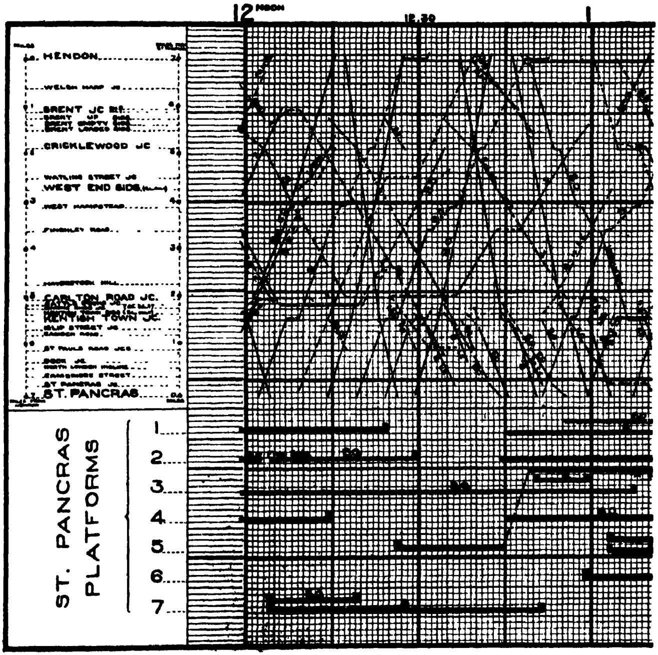


FIG. 22.
Part of Train-working Diagram, St. Pancras-Hendon, Midland Division, L.M.S. Below is seen the diagram which shows duration of platform occupancy by trains between arrival and departure times.

proportion of the total preparation which must be made by the time-table staffs, ere a new time-table comes into force. All the various time-table books have now to be compiled.

Here again the time-table books sold to the public and the sheet time-tables exhibited at the stations form but a fraction of the time-table matter which has to be printed. For the railway operating staffs themselves, " working " time-tables are compiled. Those who tear their hair over the complexities of Bradshaw's Railway Guide might rapidly be reduced to complete baldness if they were left to the mazes of a railway staff time-table. These working books show, not only the passenger trains, but empty trains and light engines, and also—except in the case of those railways which issue separate freight working time-tables—all the regular goods and mineral trains. The freight time-books are similarly compiled, with much added information as to the marshalling and working of the trains.

In the case of non-stopping trains, the times are given at which they are expected to pass all the principal stations and junctions *en route*, in addition to their times of departure and arrival. These passing times are of considerable importance, as they enable signalmen and others to know exactly when the fast trains should pass important traffic centres, and this knowledge, in its turn, allows of the carrying on of shunting or other operations affecting the main lines, without either delaying the expresses, or keeping the main lines clear for indefinite periods. Various other details have to be included, so that the complete working time-tables for a railway group form a large and bulky volume, far exceeding in size the time-table issued to the public. The complete Great Western working book, for example, is a mighty tome of some 2,000 pages, divided into fifteen geographical sections. Each driver, guard, signalman, stationmaster, and other member of the staff who is directly connected with the working of the trains, receives the section or sections of the book with which he personally is concerned but not the whole of it. The preparation of

the working time-tables is therefore a considerably more complicated task than that of the public book.

But this is not all. When the time-table has been planned, and to a certain extent while it is being planned, arrangements have to be thought out as to the working of the locomotives and rolling stock. Locomotives, as we have seen in Chapter IX, must if possible be returned to their sheds for cleaning and attention within the compass of every twenty-four hours. Coaching stock, of which the supply is far from unlimited, is made up when practicable into " sets," which have their own home stations ; in some cases these sets work out and home daily, but in others complicated itineraries may be followed, taking coaches away from the stations at which they are based for two or three days consecutively. If the most careful rosters were not worked to in connection with the disposition of passenger rolling stock, the condition of affairs might soon become chaotic. So the actual formation of each train has to be considered with great care, and diagrams, load lists, engine workings, and many other data, have to be prepared in connection with every new time-table issue, and printed and circulated well in advance so that due preparations may be made. Still more important than the round working of the rolling stock is that of the staff, which entails yet further printed arrangements.

Last of all, provision has to be made for all the special workings which take place, involving the putting on of special trains, or the duplication, at times of pressure, of existing trains. It is but rarely that specials are chartered at a moment's notice, and such trains can only be advised to stations and signalmen concerned by wire ; but the great majority of special workings are incorporated in a " Weekly Working Notice," which forms a weekly supplement to the working time-tables. Then, again, it is of vital importance

own control is always a vexed question. The favourite argument advanced against the practice is that it might lead to a driver taking undue risks and running at dangerously high speeds in order to effect this recovery. Experience proves, however, that in Great Britain this is a negligible risk, seeing that for twenty years past no serious British accident could be cited in which the primary cause was excessive speed, arising out of a desire to make up time. On the other hand, apart from the safeguard of the signalling, there might be serious risk arising out of a time-table thoroughly disorganized by late running. For this reason there is a distinct tendency among the higher railway officers, at the present time, to encourage drivers to make up lost time, when this can be done without risk, and so at the earliest possible moment to restore their trains to their time-table paths. The French go even further, and offer their drivers a monetary bonus for making up lost time, although the wisdom of this practice is possibly open to question.

It should be mentioned at this stage that one of the duties of each railway guard is to keep a "journal," or log of each run that he makes, in which all the starting and stopping times, as well as the more important passing times (in the case of an express), must be shown. In these journals all lost time must be accounted for, and many are the arguments between guards and drivers as to whether the lost minutes shall be debited "to engine," or to traffic or permanent way delays. For time lost by the engine the driver is, of course, responsible, whereas the permanent way delays are the responsibility of the Civil Engineering Department, and the traffic losses, as we have seen, may arise from a variety of causes.

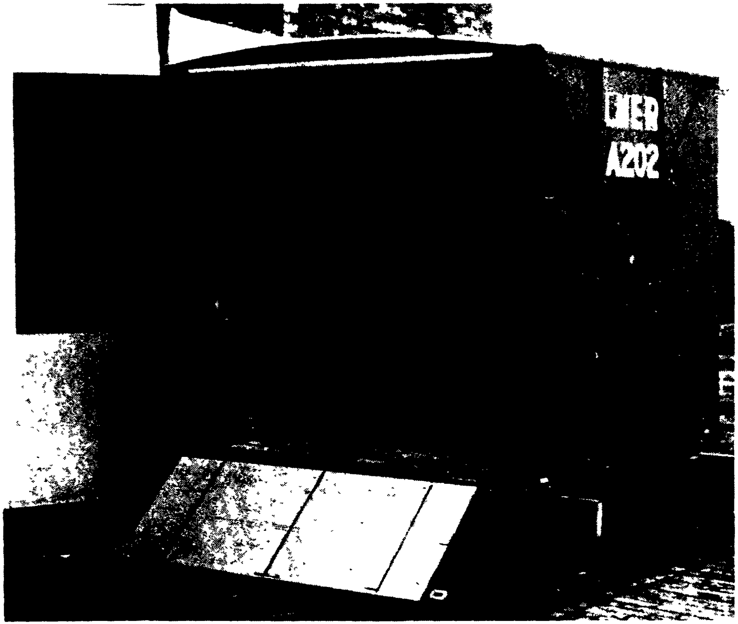
The nearest approach to perfect conditions in regard to time-table observance is obtained on underground electric

Wagons running off "hump" on to "grid-iron."

Pl. 148.

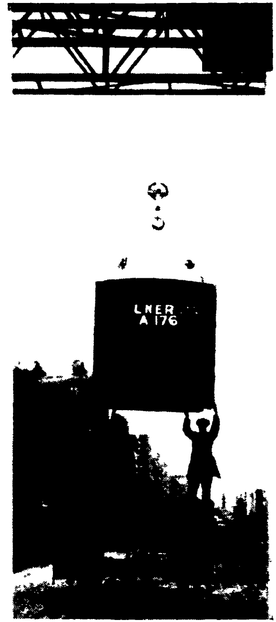
Electro-pneumatic signal cabin (p. 289).

Wath Marshalling Yard, L.N.E.R.



P. 149.

Construction of Container.



U 303.

Lowering Container on to railway wagon.

"Container" Transport of Freight (p. 289).

railways. The electric power itself is constant, so that, except in the rare event of power station or transmission trouble, no delays can arise comparable to those resulting from a badly steaming locomotive boiler. Lost time due to overloading of engine is unknown, as, with multiple-unit trains, each increase in the load is accompanied by a corresponding increase in the number of motors available. No heavy luggage is conveyed, and passengers are accustomed to rapid movement on and off the trains. The trains themselves are timed, generally speaking, at perfectly even intervals, and there are no long-distance trains, and, still more important, no freight trains, to upset the working. Practically all the ordinary sources of delay are thus eliminated. Time-tables of electric services make free use of half-minutes as well as of full minutes ; to a certain extent, also, the half-minute makes its appearance in main line working time-books, especially those of the Great Western Railway.

It is appropriate that in this chapter some reference should be made to the method of controlling the work of freight train operation. As previously mentioned, all the regular freight services figure in the ordinary working time-books, though in the case of certain railways—notably the L.M.S.—the passenger and freight services for each section are divided into separate books. But it was realised many years ago that to work freight traffic to a time-table exclusively resulted in a great deal of wasteful operation of trains. Owing to the fluctuations in traffic, the engine of one freight train might run with a part load only, whereas another freight train might be so overloaded as to require double-heading or division. These are but two of the many possible happenings which stress the need for the various depôts on a main line, at which freight is handled, to be in close and constant touch with each other, so that the

maximum possible use may be made of engines and rolling stock.

It was Mr. Cecil Paget, then General Superintendent of the Midland Railway, who was the first in this country to realize the vast importance of a centralized form of freight traffic control, and it was on that railway, in 1909, that the first British control system was installed between Cudworth and Toton Sidings. The result was that delays to freight trains in that area were practically eliminated, and so marked an improvement of freight train working set in that it was decided to extend the control over the whole of the Midland system. Further, the decision was reached that the control should embrace passenger as well as freight working. The only other railway which followed the Midland, prior to the railway grouping, in extending traffic control to the whole of its system—the complex ramifications of which lent themselves admirably to such a method—was the Lancashire and Yorkshire. But on practically all the British main lines handling heavy freight, some system of traffic control is now in evidence, and the value of the method is beyond question. It has sometimes been called "train control," but that is a title referring more appropriately to automatic train-stops and other similar devices for automatically controlling the working of locomotives from the track; "traffic control" is the more correct designation.

It may now be of interest to examine briefly the working of traffic control. The Midland method differs from others chiefly in the matter of its completeness, but it may be taken as typical. The "brain" of the whole system is centrally located at Derby, where the main control office is situated; the line itself (the Midland Division of the L.M.S. system) is divided into 25 areas, each with its own control office, in direct telephonic communication with the

central control office. Various strategic points in each area are charged with reporting by telephone to the local control office, at two-hourly intervals throughout each day, the exact disposition of all the wagons in the immediate vicinity of these reporting points, whether empty and on hand, or on the premises of the consignees, or waiting acceptance, and so on, as well as the amount of traffic on hand waiting to be loaded. This information is entered on large sheets, on which a close watch is kept, in order that the wagons may be distributed exactly when and where they are needed.

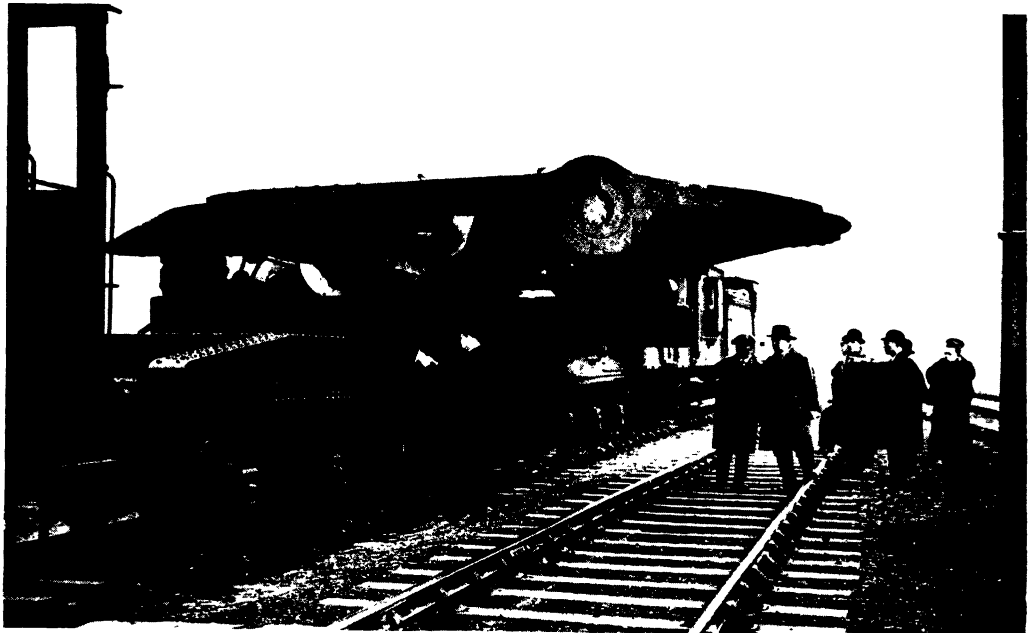
On large time-table diagrams—of the kind previously described—all the possible paths for freight trains have been plotted, so that the local control office knows exactly when trains may be dispatched within its area, in addition to regular daily workings. The reporting points advise the control staff of the exact movement of each freight train, all the trains moving within each area being represented graphically on large boards displayed at the control office. Vertically each of these boards represents a section of line governed by the control office, and horizontally the board is divided into the twenty-four hours of the day, split up into five-minute intervals. Each train appears as a card, of a colour varying according to its character; on the card is entered the number of the engine, the load, the names of driver and guard, and the times at which the train passes the more important timing points. Throughout the day and night these cards are moved gradually across each board, according to the position of the train concerned, so that the whole condition of the freight traffic within the area controlled by the district control office is visible at a glance.

There is little need to labour the advantages of such a system as this; unnecessary workings can be cancelled; partly-loaded trains can be stopped where they need to be

made up to full loads ; a watch can be kept on the time of all the men within the area, and overtime or lodging away reduced to a minimum. It fulfils, in brief, the purpose of traffic control, which is that engine-miles and train-miles shall be economized where possible, that wagons and trains shall be loaded to full capacity, and that they shall be moved as quickly as possible. Every day the various local control offices send various detailed returns to the central control at Derby, and telephonic conferences are carried on as to the freight position in each area, and the solution of any special difficulties.

The similar control of passenger working was introduced on the Midland system in 1917. Control extends only to the principal express trains, the exact position of all of which can be seen, at any moment of the day or night, on the passenger train control table (Plate 152). Long brass slides represent each main line, and clips which move along them hold cards, each representing a train. On the cards are entered the necessary particulars concerning each train. If extra stock is required to be attached to any train, " control " must first be asked, and instruction is then given as to where the required vehicle may be found, where it is to be added, at which end of the train, and so on. In this way close watch is kept on the whole of the rolling stock running over the line, both passenger and freight, and the central control office at Derby functions as the brain of the whole system.

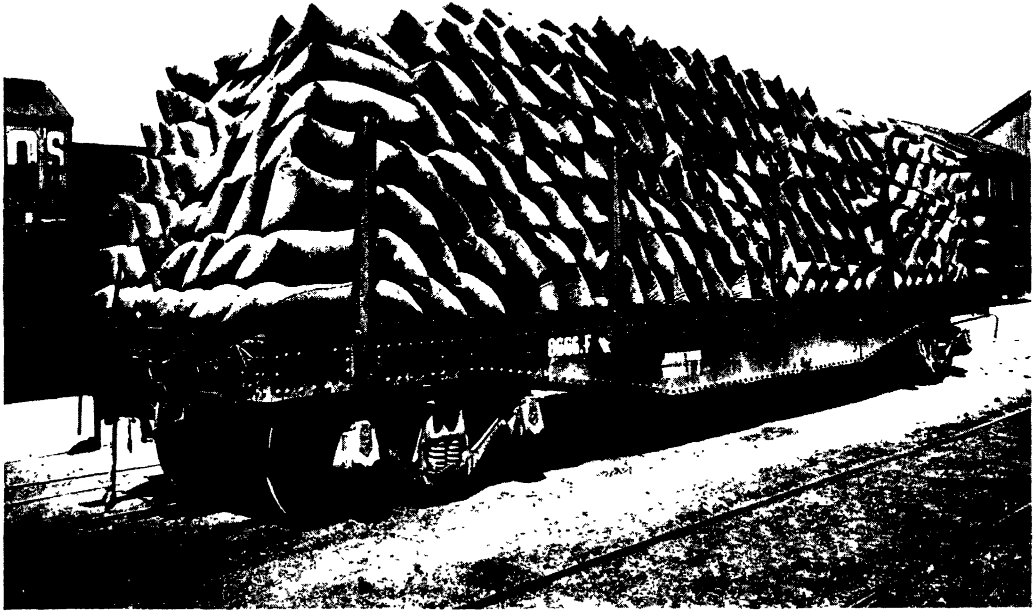
The traffic control arrangements in force on other lines are of much the same description, though the Derby control is probably the most complete of any. A particularly ingenious system is that used for control of the traffic, both passenger and freight, over the East Coast main line of the L.N.E.R., between York and Newcastle. Instead of the carriers representing the various trains being moved



Pl. 150. X 306.

An Out-of-Gauge Load—The Rudder of S S "Aquitania" en route from Darlington to Middlesbrough

L.N.E.R. (p. 290)



Pl. 151. X 307.

An Exceptional Load of Grain, South Australian Railway (p. 289).

individually by the control staff with the receipt of each fresh telephonic advice, they are arranged to move automatically on endless cords, worked by a clockwork mechanism. Of these cords, which move from one side of the control-board to the other, there are five to represent each direction of running, the movements of which are calculated to correspond as nearly as possible with the speeds of express passenger trains, intermediate passenger trains, and freight trains of Classes "A," "B" and "C" respectively; and for the same reason the board is planned on a scale of average speeds rather than of exact distances. Theoretically, therefore, the carrier representing the train concerned moves across the control board at its average booked speed, but brass stops are fixed on the board, in connection with each cord, to prevent the carrier of a train from getting past one of the control points before that control has actually reported its passage. Similarly, in the event of a train running at a higher speed than that scheduled, the fact that the carrier has not reached the stop when the train is reported enables the control operator to make the necessary adjustment. Carefully-compiled lists of all the regular trains, with their intermediate timings, are fixed above the control board, so that the operators have no difficulty in hanging the carrier representing a train on to its appropriate cord, as soon as it is telephonically reported to have entered the control area. Although possibly these systems of traffic control take away from the staff responsible for working the trains opportunity for showing initiative and resource in their work, yet control is undoubtedly the most satisfactory method of railway operation, especially in the case of freight traffic, and the expedition of running, as well as the economies effected by better wagon loadings, well warrant the cost of the traffic control installations at present in use.

CHAPTER XVII

Stations and their Staffs

BETWEEN the railway station practice of the British Isles and that of other countries in the world there are some wide divergences. In Great Britain the passenger, having taken his ticket at the booking office, is accustomed to pass straight through to the platform, and there to wait for his train. On the Continent and in America, it is far more common, especially at the larger stations, for the passenger to remain in the station buildings until the arrival of the train, and not until then to be admitted to the platform. This difference of method has led to a corresponding difference in the planning of the stations themselves. In this country every platform is generally provided with waiting room and other accommodation for passengers, whereas in other countries more commodious offices are provided for all the passengers in the main station building. In America, in particular, the passenger accommodation of many of the main stations is exceedingly fine, excelling the best of this country ; but we, on the other hand, should think but little of the accommodation for the trains themselves, which is called the " train shed," being merely used by passengers for the purpose of walking to and from their trains. In this connection the low winter temperatures of the North American States must not be forgotten ; waiting for a train on an exposed platform in mid-winter would be out of the question in North America or Canada, with the thermometer possibly below zero.

The platforms in Great Britain, again, differ in type from those used in most other parts of the world. It has been the general custom in Great Britain to provide every coach compartment with its own door, except in the case of a small proportion of the main line corridor stock, and to allow passengers to step from the compartment to the platform on a level just below the compartment floor. This method requires the use of a platform some 3 ft. above the rail level; the purpose is that of handling passengers with the maximum possible rapidity. In other countries, however, the coach with side corridors and end doors only is, with few exceptions, in universal use, passengers having to climb up and down from and to the ground by means of end stairways. Thus in most other countries platforms are practically non-existent (Plates 157 and 159). This is one reason, by the way, why the Continental or the American locomotive looks so immensely large, to the casual observer, by comparison with our machines, the former being seen invariably from ground level, whereas the British locomotive is generally observed with some 3 ft. of its height cut off by the height of the platform alongside which it runs.

Country stations in Great Britain are of various types. Of these the most unpretentious is the "halt"—a counterpart of the French "halte"—which in Great Britain is associated chiefly with the motor-train or the rail motor-car. In some cases, where tickets to and from the halt are issued on the train, the halt may consist of nothing more than a very short platform, with, perhaps, a shelter for waiting passengers, and may require no staff. Many such halts have been opened in Great Britain in recent years, especially on routes passing through well-populated areas, in order to break up the distances between the ordinary stations, and thus to enable the railway to give, as nearly as possible, the

"door-to-door" facilities offered by road transport. Such increased facilities, again, are made available to the public without the expense entailed in building and staffing additional stations of the ordinary type. At many minor stations, also, where passenger traffic is small, and the only other traffic is that in parcels, a staff of one or two is frequently found sufficient to handle the work, and, as mentioned in an earlier chapter, one stationmaster is entrusted with the supervision of several adjacent stations.

The majority of stations, both on main and branch lines and whether the line concerned be single or double, are provided with separate platforms for the two directions of running. On single lines the track is generally expanded from single to double over a "loop" through the station, more than sufficient in length to accommodate the longest train likely to run over the route concerned. A loop of this character is important, as it permits of the "crossing," or passing of up and down trains. Where stations on a single line are some distance apart, the station loops are supplemented by others at intermediate signal-boxes.

A method of station planning sometimes adopted for a double-line station is to enclose one single platform, which serves both roads, between them in the form of an "island," reached either from a road overbridge or by means of a footbridge. There are various advantages, as well as objections, attaching to the "island platform" station; the chief advantage is that all the station offices are located on one platform instead of two, but a slight disadvantage is that reverse curves must be arranged in each running line, in order to carry the tracks round the platforms. On the London Extension of the late Great Central Railway, from Calvert to Hucknall—a distance of 84 miles—the whole of the stations are so laid out, with the exception of the three in Nottingham; but the reverse curves are of not

By courtesy] [*L.M.S.*

Pl. 152. X 310.

Passenger Train Control Table, Derby, L.M.S. (p. 306).

The slides can be seen extending the whole length of the table, with the clips for the cards indicating the whereabouts of trains, and the numerous telephones.

Pl. 153. X 311.

Interior of Waterloo Station, Southern Railway, Showing Concourse (p. 313).

less than a mile radius, and are traversed with perfect smoothness at the highest speeds. Even the important station at Leicester is on the island platform plan, with one lengthy platform between the up and down main lines, 1,245 ft. long, and four additional " bay " platforms for local trains, two at each end. A " bay," as its name implies, is a terminal platform or platforms, arranged alongside through platforms, and one or more bay platforms may be found at most large through stations. It should be added, also, that any platform which has through tracks on both sides is strictly an island platform.

There are one or two remarkable stations in this country at which the main line traffic is dealt with at a single platform ; not on opposite sides, however, but on the same side. Cambridge, on the L.N.E.R., is a notable example. The down main line trains make use of the north end of the platform, which has a total length of 1,677 ft., and the up trains use the south end, the necessary access being given by a double, or " scissors " cross-over road at the centre of the station. The method has little to commend it, as all up and down passenger trains have to cross each other's paths on the flat, both in the centre and at the south end of the station, but opposition in the town has prevented the rebuilding as a double-line station which has been proposed, and even planned, in years gone by, so that the lay-out of Cambridge Station is now but little likely to be altered in the future. The working at Cambridge has, however, been greatly improved of recent years by the installation of a fine power-signalling plant, controlling the whole of the working of the station and its approaches.

The distinction of owning the longest station platform in the British Isles now belongs to the L.M.S. Railway in Manchester, where, by the merging of the adjacent Victoria and Exchange Stations, owned respectively by

the late Lancashire and Yorkshire and London and North Western Railways, one immense platform has been laid out no less than 2,240 ft. in length. Hitherto the record has been held by the main island platform at Perth General Station, 1,750 ft. in length, followed by the principal up platform at York—No. 4—which is 1,692 ft. long. Other very lengthy through platforms are found at the Waverley Station, Edinburgh, the longest of whose up and down main platforms measures 1,680 ft.; Aberdeen Joint Station, with one through platform 1,596 ft.; and Crewe, with a number of very lengthy platforms, one 1,509 ft. long. In all these cases, scissors crossing connections at the centre of each long platform give independent access to both ends of the platform; such provision is of the greatest value, not only as providing standage for two trains at once, but also as facilitating the complicated operations of train marshalling which take place at each of the stations mentioned.

The adoption of a similar plan at terminals is open to objection on account of the distance which must be covered by passengers to and from trains berthed at the outward ends of the platforms, between train and platform exit. The Brighton side of Victoria terminus in London is practically the only example of this type of planning at a British terminal. Early in the present century the increasing traffic at Victoria compelled an enlargement of the then existing station, and as it was impossible to obtain room for any lateral extension, the only practicable increase in size was longitudinally. In the enlarged Victoria, opened in 1908, the inward part of the station consists, for the major part of its width, of two-track bay platforms, of the usual type; but from the centre of the station outward, certain of the platforms are narrowed sufficiently to allow of the laying in of a third track, between the two platform tracks,

affording entrance to, and exit from, the inner ends of six of the platforms, when the outer ends are occupied by trains. The largest platforms at Victoria are 1,500 ft. in length. Since the grouping of the railways, the South Eastern and Brighton sides of the station have been opened out into each other, the combined terminus being one of the largest in London; its total of 17 platforms, now numbered consecutively from one side of the station to the other, is equivalent, as we have just seen, to a virtual total of 23 platforms. The platforms of the High and Low Level Stations at London Bridge, Southern Railway, are also now numbered consecutively, and reach a total of 22, though this could hardly be regarded as one station in the same sense as the combined stations at Victoria.

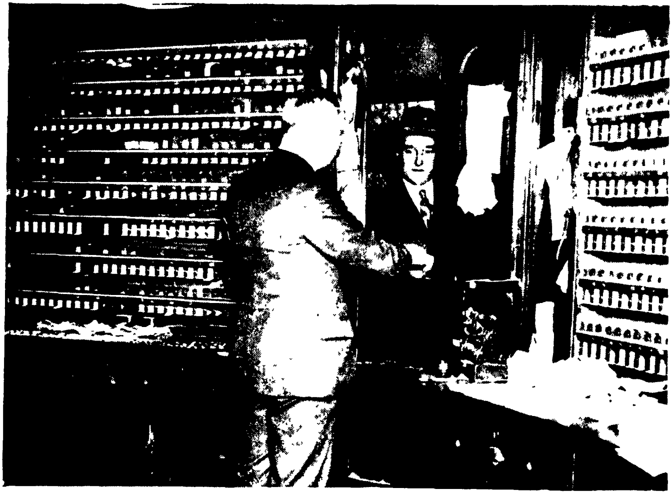
But it is the Waterloo terminus of the South Western section of the same group which is, with little question, the finest of our London stations—the more notable, too, in view of the miserable and labyrinthine range of buildings around and over which, without interruption of traffic, it was built. Waterloo to-day has 21 platforms, with an aggregate length of 14,628 ft., and handles a total of 1,180 trains daily, the great majority of them electrically-operated. The finest feature of the station is the immense "concourse," or circulating area (Plate 153), extending the full width of the station, with the range of station buildings on one side of it and the platform entrances on the other. It is of interest to note that the all-over glazed roof at Waterloo, covering 560,000 sq. ft., absorbed 1,000 tons of glass, and 60 miles of metal glazing bars. Liverpool Street terminus of the L.N.E.R., accommodating the huge suburban traffic of the late Great Eastern Railway, beats Waterloo in the number of daily train movements, of which there are 1,200; as regards passengers handled daily, Liverpool Street is without a rival in this country, handling

as it does a total of roughly a quarter-of-a-million passengers in the twenty-four hours. All this enormous traffic is worked over three inward and three outward roads, and a large proportion of the suburban trains spend no more than 4 minutes in their occupation of any one terminal platform. Passenger exit from platforms is facilitated by the ingenious method of arranging circulating space between platforms, on the platform side of the exits, as well as the main circulating area, so that passengers leaving and joining trains have the choice of a large number of gates through which to pass. As regards the maximum number of trains passing through, the record is held easily by Clapham Junction of the Southern, which, with its 17 platform lines and many other through tracks, is estimated to handle 1,730 trains daily; station and sidings here cover between them some 35 acres of land. Out of London, the Waverley Station at Edinburgh, with its 19 platforms, totalling in length 13,980 ft., and its occupied area of 18 acres, probably takes the lead in train movements, which total roughly a thousand daily.

In the matter of size, though not in density of traffic handled, there are a number of Continental and American stations which could rival the largest yet built in this country. In some large cities, at immense cost—an adequate return on which, as a result of subsequent economies in working, is somewhat problematical—separate terminal stations of different railways have been abandoned in favour of one central terminal of very large size. The new central station at Leipzig in Germany (Plate 158) is a case in point; it has 26 tracks, through which pass the larger part of the traffic between Prussia and Saxony, occupies an area of 172,000 sq. ft., and with the connections through the city, including various flying and burrowing junctions, entailed an outlay of 6½ millions. In Paris the St. Lazare

Pl. 154. X. 314.

"Passimeter" Booking-Office, Oxford Circus, London Electric Railways (p. 317).



Old type booking office, with ticket-cases to left and right, and dater to right of window.

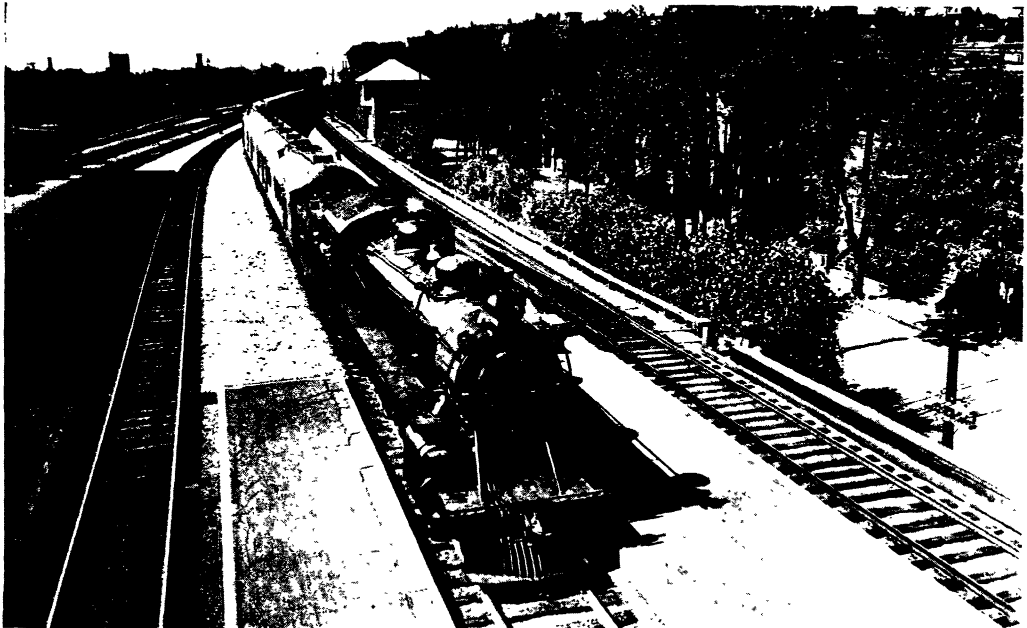
Pl. 155. *X* 315.

›ooking office, with automatic ticket-printing mach and change machine to left.

The Old and the New in Booking-Offices (p. 318).

terminus of the State lines (Western Division) has 31 tracks and handles 1,200 trains and approximately 250,000 passengers a day, some part in the transport of whom, as we saw in a previous chapter, is played by double-decked passenger coaches. Ere long this record will be beaten by the Gare de l'Est in Paris, now in course of reconstruction, which is ultimately to have no less than 30 platforms in place of the previous 18, all from 900 to 1,000 feet in length. To serve these there will be three inward and three outward running lines, together with three additional lines for locomotive and empty carriage movements. The front of the station will be adorned by one continuous *façade* of no mean architectural pretensions, 525 feet long. It is anticipated that the work of rebuilding and extension will continue until 1931, and will cost in all about £3,000,000. In 1925 the Gare de l'Est handled 25,500,500 passengers, and the number is still increasing; to-day between the hours of 6 and 7 p.m. alone some 23,000 outgoing city workers present themselves for transportation home.

The most remarkable railway terminal station in the world is probably the Grand Central terminus of the New York Central and New York, New Haven and Hartford Railroads in New York City. It is estimated that the total cost of this vast structure, with the under-river approach tunnels, was in the neighbourhood of 30 million pounds of which the station, station buildings and the land they occupy accounted for 23 millions. The underground station proper occupies a site of 80 acres, and required the excavation of no less than 3¼ million cub. yds. of material, mostly rock. The trains are on two levels, the long-distance station, with 42 tracks, being 20 ft. below the street level, and the suburban station, with a further 25 tracks, 44 ft. below. An immense concourse, communicating with every part of the station, 275 ft. long



Pl. 157. X 319.

The "Trans-Canada Limited" Running into Windsor St. Station, Montreal, Canadian Pacific Railway (p. 309).

CHAPTER XVIII

Signals and Signalling

It has sometimes been claimed, more, perhaps, in joke than in earnest, that the world knows no safer place than the inside of a British railway train. But the claim is, after all, no idle boast. In three separate years since the beginning of the present century—1901, 1908 and 1925—not a single passenger lost his or her life as the result of an accident to a British train in which he or she was travelling. During the years 1918-1927 the number of fatalities among British passengers, caused by railway accidents, averaged eight per annum, out of a total number of passenger journeys estimated roughly at two thousand millions annually. No other country in the world could claim such immunity from accident as this. Safety in British railway travel is in large measure due, without question, to the methods of signalling by which the movement of the trains is controlled ; the present systems are the fruit of many years of development, as a result of which the laws of this country relating to railways now compel the installation and working of railway signalling of certain approved descriptions.

Soon after the establishment of the first railways it became evident that, as the speed of the trains was likely to exceed greatly that of the horse-drawn vehicles on the roads, some form of signalling would be necessary in order to prevent one train from running into another. The first semaphore signals were introduced before the electric tele-

graph, and trains were run on a "time interval" basis, that is to say, after a certain lapse of time subsequent to the passage of one train, the next was allowed to proceed. If the interval between trains had been one of fair length, the second train might be permitted to proceed at full speed; otherwise, with the first train but a short distance ahead, the second was allowed to proceed cautiously, in order to avoid the possibility of collision—especially as, in those days, screw hand-brakes only were available for stopping—with the train preceding. The early railway semaphore signals, therefore, had three positions of their movable arms—the horizontal position, as always, indicated "STOP"; the half-way position, at an angle of 45 degrees with the vertical, "PROCEED WITH CAUTION"; and the vertical position, with the arm concealed in the slot in the signal-post, "LINE CLEAR—PROCEED AT FULL SPEED."

Cooke and Wheatstone's electric telegraph was first installed on the Great Western Railway, between Paddington and Slough, in 1839, and by the use of this electric communication the whole problem of railway signalling has been modified. Except in certain special cases, to which reference will be made in a moment, the three-position semaphore has now given place to one with two positions only—"ON," the horizontal position, indicating danger, and "OFF," the 45-degree position, showing "LINE CLEAR." Hitherto in Great Britain the "off" position has always been "down" or in the lower quadrant, but the future standard for British railways is to be an arm which will rise into the upper quadrant when pulled off; this new standard semaphore is illustrated in Plate 169. These positions are repeated at night by means of a spectacle containing red and green coloured glass, moving in front of a lamp at the side of the arm. With the arm in the horizontal, or danger, position, the spectacle shows

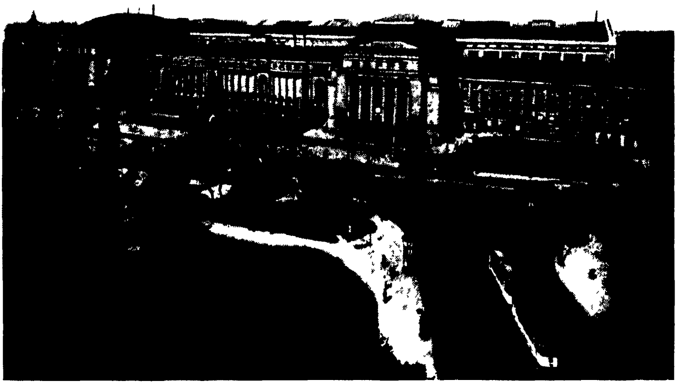
a red light at night, and when the arm is "off," the light indication is green, again apart from certain variations shortly to be mentioned.

The general principle of working which has developed is known as the "block system." For this purpose every route is divided up into "block sections," and each section is controlled by a signal-box with fixed signals. The term "fixed" signal, by the way, is merely used to distinguish the permanently-installed mechanical signal from indications given by hand or with a hand-lamp. The principle of block working is that no two trains shall be allowed in the same section at the same time, the signals governing the exit from any block having to be returned to danger after one train before the next train is permitted, by the signals controlled from the preceding signal-box, to enter the same block. Strictly speaking, the block is the portion of the line intervening between the outermost of the signals controlled by the adjacent signal-boxes; it may vary in length from many miles, on routes carrying but sparse traffic, down to what is virtually no length at all, as on the busiest suburban routes some of the block sections, shortened in order to permit a maximum frequency of service, actually overlap each other. Communication from signal-box to signal-box is made by a code of bell signals, and by special electric instruments which give a clear visible indication as to whether or not the block on either side of the box concerned is occupied by a train.

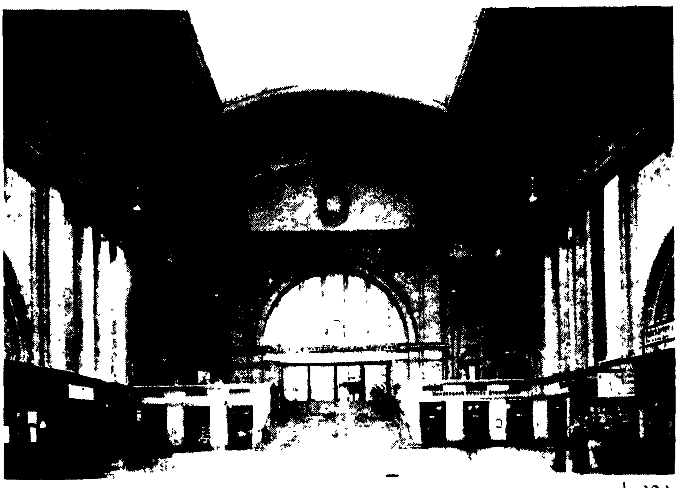
Before the working of the block instruments is described, it may be well briefly to describe the construction of the signals themselves. The familiar semaphore signals (Plate 163) are largely in the majority. These are provided with arms about 5 ft. long, mostly thin boards, but on some lines (as, for example, the Western Division of the L.M.S.) of corrugated sheet steel. The pivot of the arm runs through

the centre of the signal-post, or else, on the Great Western Railway, for instance, is carried in a bracket outside it. The late Great Northern Railway, after a serious accident at Abbot's Ripton in 1876, decided on the "somersault" type of signal-arm (Plate 162), which is pivoted in the centre, instead of at the end, and carried on a long bracket extending outward from the post. When the Great Northern arm is "off," it stands in a vertical position, away from the post, and is considerably the clearest to drivers of all semaphore signal indications; but it is, on the other hand, a more expensive type of construction than the ordinary semaphore, and in virtue of the signal standardization now decided on, it is doomed to extinction. The accident just referred to arose out of the old practice of carrying the semaphore arm in a slot in the centre of the signal-post, instead of on the outside; during a blizzard, the slot of one of the Abbot's Ripton signals became choked with snow, so that the signal did not return to danger when the lever was released in the box, and a disastrous collision resulted.

The front of the semaphore arm is painted red, with a white stripe near the outward end (or, in the case of certain distant signals, described presently, yellow with a black stripe) and the back white, with a black stripe; the white stripe is to make the arm better visible against a dark background, and the black stripe on the back, conversely, to show up the arm against a background of sky. As seen from the red or yellow side, which are the only sides to concern a driver, all semaphore arms point to the left of the posts to which they are fixed. The pivot of the arm forms part of an iron casting, to which the arm is fixed, and also the spectacle frame which holds the coloured lenses; to the latter, in its turn, is attached the rod from the base of the post which actuates the arm. It is important to note that the weight of the spectacle, in the existing



Exterior Elevation.



Pl. 158. F 322.

Interior showing Main Circulating Area.

One of the most notable Stations in Europe, The New Leipzig Central Station, German State Railways (p 314)

Pl. 159

A Typical Continental Station Interior (p. 309).

type of semaphore, is more than sufficient to balance the arm, so that the latter would return to danger even in the event of breakage of the signal wire or any part of the mechanism on the post. In the new standard semaphore, which rises when pulled off, there is no such balance, but the weight of arm and spectacle would cause the arm to drop to danger immediately, should any breakage occur. The weight on the actuating lever at the foot of the post is merely designed to keep in a taut condition the wire from the signal cabin.

Main line signal arms are divided principally into two classes—those with square-ended semaphore arms, and those from the outward end of whose arms a small notch has been cut, so that the arm appears to be fish-tailed (Plate 163). The former are stop signals, which must not be passed by a driver when they are in the "on," or danger, position; the latter are known as "distant" signals, but being designed merely to indicate to a driver the position of the next following stop signals, they may be passed when at danger. The purpose of distant signals is to give a driver adequate warning of his approach to signals at danger, and sufficient room in which to pull up—a consideration of no small importance when it is realized that the gross weight of a modern express, travelling at 70 miles an hour and more, may be over 600 tons. At certain locations, where it is necessary that all trains should reduce speed—as, for example, at the approach to a terminal station—distant signal arms are fixed permanently in the "on" position, and the light exhibited at night is permanently red.

For more ready distinction between stop and distant signals, the London and North Eastern and Great Western Railways have recently followed the lead of the Underground lines in painting all their distant signal arms yellow instead of red, and substituting orange for red as the

"danger" indication for distant signals at night. Some years ago the Southern Railway adopted the Coligny-Welch distant signal lamp, which shows an illuminated white fish-tail at night against the distant signal lamp (Plate 163), but even this expedient does not get over the objection that a driver has to pass a red light when he passes a distant signal at danger. The substitution of orange does, however, get over the difficulty, and its clear indication is much appreciated by the engine-crews. In the new standard upper-quadrant signals yellow arms and orange lights are used exclusively for distant signals.

The stop signals controlled by a signal-box are grouped, as far as possible, within the sight of the signalman, as it is important that, if he is compelled to stop a train, as a result of not having received "clear" from the box next in advance, the train shall stop well in his view. Various ways in which his memory is assisted, and the working of his box, indeed, controlled by mechanical and electrical means, will be mentioned later. The stop signal first reached by the train—and generally before the engine is abreast of the box—is the "home" signal; this is in most cases supplemented by an additional stop signal, beyond the box, known as the "starter," which governs the entrance into the next block section. Between the "home" and the "starter" a signalman can allow a train to draw within the protection of his signals, the "home" signal protecting the rear of the train, whereas the "starter" forbids the driver to proceed into the next block; this is frequently of value, for example, at a station, where the "home" is at one end of the platform and the "starter" at the other, so permitting a train to draw up to the platform, past the box, even though the block ahead is not clear.

In many instances, however, additional stop signals must be provided. Most common of these is the "advanced

starter," located, as its name implies, beyond the " starter "; this is usually when a siding or other connection comes out on to the main line ahead of the " starter," and enables a signalman to lower his " starter "—in order that a train may draw forward, for example, before shunting—without the train passing beyond the protection of the signals controlled by the box. In certain cases, also, the " home " is supplemented by an " outer home," some distance further away from the box ; " outer homes " are provided,

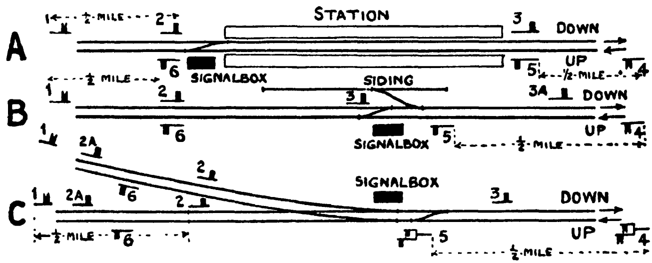


FIG. 23.—Typical Sequences of Signals.

(A) Double line station, with starting, home, and distant signals.
(B) The same, with siding on down side, ahead of starting signal, necessitating use of down advanced starting signal.
(C) Double line junction, with down outer and inner home signals.

References ;—
1.—Down Distant Signals. 2.—Down Home Signals. 2A—Down Outer Home Signals. 3—Down Starting Signals. 3A.—Down Advanced Starting Signal. 4.—Up Distant Signals. 5.—Up Home Signals. 6.—Up Starting Signals.

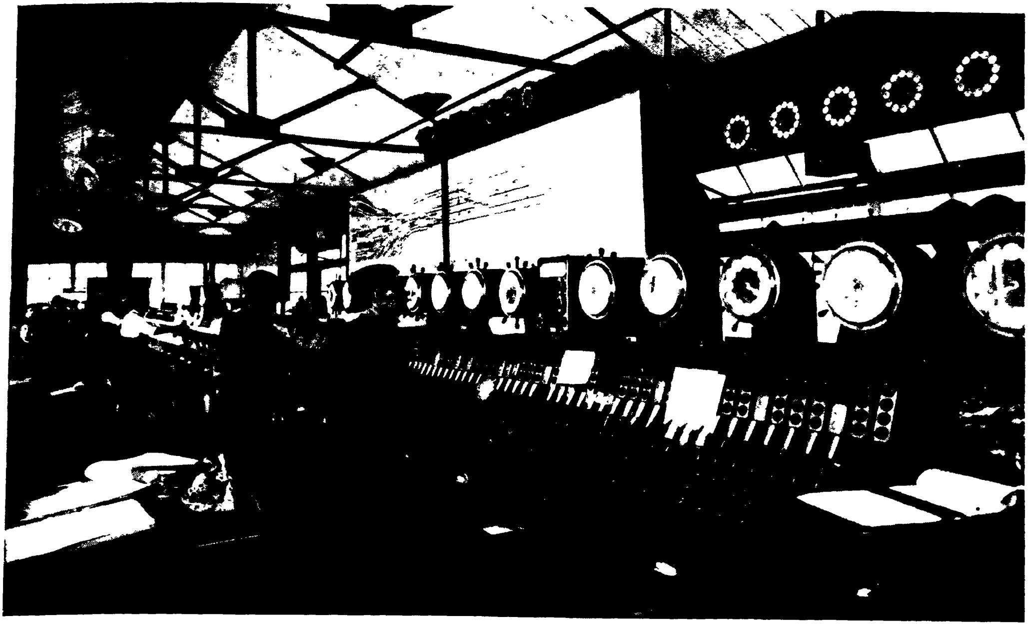
in particular, to protect the converging lines at junctions, where the overrunning by a train of the " home " signal might have serious consequences.

The sequence in which the various stop signals controlled by a box are passed by a driver is, therefore, " outer home," if any, then " home," then, generally, the signal-box itself, then " starter " and, last, " advanced starter," if any (Fig. 23). Roughly half-a-mile before reaching any

of these, however, he has passed the "distant," the distinctive character of whose arm and light has been already mentioned. The "distant" being a warning to the driver as to the position of the stop signals controlled by the same box, it is in some respects—and to the driver of an express train in particular—the most important signal in the section. For the same reason it is impossible for a signalman to lower his distant signal until all his stop signals governing the same direction of running are also "off"; this is controlled by mechanical locking under the floor of the cabin, to which also later reference is made.

It is important that the signalman shall know accurately whether or not the movement of his levers has actuated the signals concerned; when the signal is invisible from the box, as is generally the case with distant signals, he is provided in the box with electrically-controlled miniature arms (Plate 164) which "repeat" the position of the signal-arm concerned. As regards night identification, when the signalman cannot see the front spectacles of his signals—whose red, yellow or green indications would show him if they are correctly "on" or "off"—a small white "back-light" from the lamp is visible to him, which is automatically obscured by a revolving plate when the arm is pulled off. The repeaters of signals which are invisible from the box serve their purpose equally by day or night; but the important point as to whether the lamps of such signals are burning correctly is recorded in the box by electric indicators, worked by means of "thermo-couples" of different metals situated above the flame in the lamps. Every possible precaution is thus taken to show the signalman if the signals under his control are functioning properly.

Up to the present we have referred only to signals whose posts carry single semaphore arms, but semaphores are, of course, employed in many combinations, some of them, to

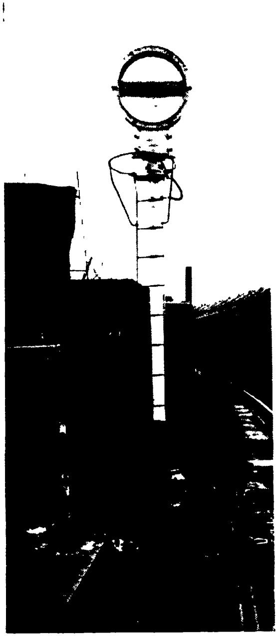


Pl. 160. *Y* 326.

The New Signal-Box at London Bridge, Southern Railway (p 333.)

The largest all-electric signal frame in the world, with 311 levers. Four-light electric signal repeaters behind levers;

Pl. 161.



Banner Signal (p. 331).

Route-indicating signal (p. 329).

Fog-repeating signal (p. 330).

Types of Electrically Worked Signals

the untutored observer, of no small complexity. Probably the most frequent of all combinations is that of a distant signal under a stop signal, on the same post (Plate 163). This occurs where blocks are very short, and, in the great majority of cases, is the "starter" of one box above the "distant" of the next box in advance. In order that a driver shall not be misled in the event of the distant being pulled off without the stop signal, it is customary to control the working of the two arms by means of a "slot"; this is a weighted mechanical device which returns the distant arm to danger as soon as the stop signal returns to danger, and prevents the former from falling, even though its counterweight be pulled off, until the latter is also pulled off. To replace the use of two arms in a case like this, a certain limited use has been made, in recent years, of "three-position" signals. These (Plate 162) are provided with one arm, which, as its name implies, has three positions; horizontal, corresponding to both stop signal and distant "on"; 45 deg. upward, corresponding to stop signal "off" and distant still "on"; and vertical, in line with the post, corresponding to both stop signal and distant "off." For night use, a three-colour spectacle is provided, showing red, orange and green in the same sequence. There is an extensive employment in America of three-position semaphores; their use in England is confined to a few installations round London.

The most complicated signal groupings are necessarily those connected with junctions. As a train approaches a junction, the driver must have a clear indication as to which route is set for him to travel over, and it is therefore necessary to have a separate signal arm for each route. In early days the stop signals preceding a junction were arranged one above another, on the same post, the top arm governing the left-hand route, and the lower arm the right-

hand. Such groupings may still be seen in places, such, for example, as the approach to and the exits from the down suburban platforms at Finsbury Park, L.N.E.R., where there are four, and in places five stop arms on the same post, indicating in succession the routes from left to right; similar groupings are commonly used, also, in goods yards. But for main line use, and especially where trains are travelling at speed, clearer indications than these are required. The general practice is, therefore, to arrange the stop signal for the route of greatest importance in the centre; the signals governing divergencies to the left are grouped on the left, and those for right-hand routes to the right. Further, the heights of the various arms above the ground are arranged according to the relative importance of the routes that they govern, with the main or fast-running road as the highest of the group. Such groupings as these greatly simplify the task of a driver in picking out his own signals, and especially that of an express driver, when passing through a busy junction at speed.

Four or more tracks approaching a junction add yet further to the signalling complications, and in short blocks the distant signals for the succeeding sections may be mounted below the stop signals, presenting a bewildering array to those who are not familiar with the principles on which the signals have been grouped. At complicated junctions which are not traversed at high speeds, and especially the approaches to large stations, where it is necessary to indicate to drivers the particular platforms to which they are to run, considerable simplification of signalling has taken place of recent years by the use of "route-indicating" signals. In signals of this type (Plate 163) the many arms that would be necessary to indicate each diverging route are reduced to one, underneath which, in an illuminated frame, there appears an illuminated letter or figure showing which

particular route is set. The British Westinghouse and Saxby Signal Company have recently devised an ingenious electrical variant of the route-indicating signal, to be used in connection with light-signalling installations. The number of the route for which the track is set is projected electrically on to a screen (Plate 161), giving a clear indication in a very compact form. Such route-indicating signals may be found at the approaches to most of the London terminal stations, and are largely used elsewhere also. Another simplification relating to junctions is that, unless more than one of the routes branching from the junction can be taken at high speed, it is seldom customary to provide more than one distant signal arm for trains approaching the junction; this is only pulled off when the junction is set for the main line or fast-running route, with the result that the distant arm at danger compels drivers for the other routes, which require a lower speed over the junction, duly to reduce speed.

Various other types of signal require mention. To describe and illustrate every variety would require more space than can be spared, owing to the lack of uniformity between the methods of the different groups, and even between different sections of the same group. "Draw-ahead" signals are mounted under stop signals, on the same post, and when lowered authorise a driver to pass the stop signal at danger, but only so far as will enable him to reach a station platform, or clear a siding connection for the purpose of shunting back, or for similar reasons—that is to say, the "draw-ahead" arm in no circumstances allows him to pass into the next section. "Draw-ahead" arms have different shapes; on the Western Division of the L.M.S. they are short arms obscuring a small white light when at danger, and uncovering it when pulled off; on the Midland Division of the same railway they are short arms

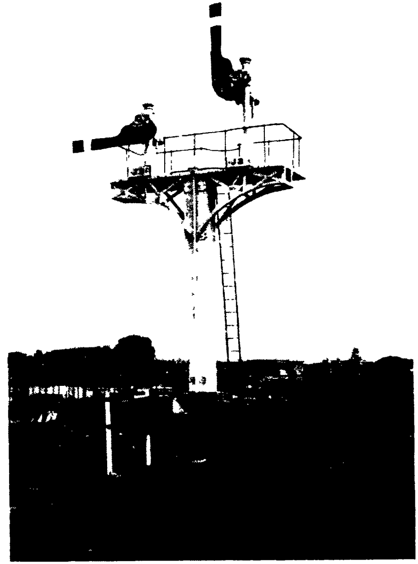
with a "T"-piece at the end; on the Great Eastern section of the L.N.E.R. they are in the shape of a diagonal cross, with cross-shaped red and green spectacle lights at night. The Great Western Railway has a somewhat similar "shunt" signal, with a short arm terminating in a large "S."

For controlling movements from main lines into sidings, over cross-over roads from one track to another, and so on, it is customary to use "ground-signals" (Plate 167). These are of various types, sometimes resembling miniature signal-arms, but being more frequently rotating lamps, which in the "on" position display a white light, encircled by a red disc, and when pulled "off" rotate, and display a green disc and light. The white light for night use was some time ago generally substituted for red in ground signals, in order to reduce the complexity of signal lights for drivers of fast trains during the night hours, and again to reduce to a minimum the passage by trains at speed of the red, or "danger" indication.

On other lines large use is made of miniature signals, or "dolls," for shunting movements, especially to control the exit from sidings on to the main line. Another use for miniature signals is that of "repeating" the movements of the ordinary semaphore signals; such repeaters are of value, for example, when the ordinary signals have been arranged at some distance from the track that they govern, in order, perhaps, to be better sighted at a distance, and an additional indication of their position is required nearer to the track, especially for use in thick weather. On certain of the open-air sections of the Metropolitan District electric lines, special "fog repeaters" are employed, consisting of light-signals (Plate 168) of great penetrating power, repeating the lights of the ordinary signals, but only switched into use at times of fog. Another special form of repeating

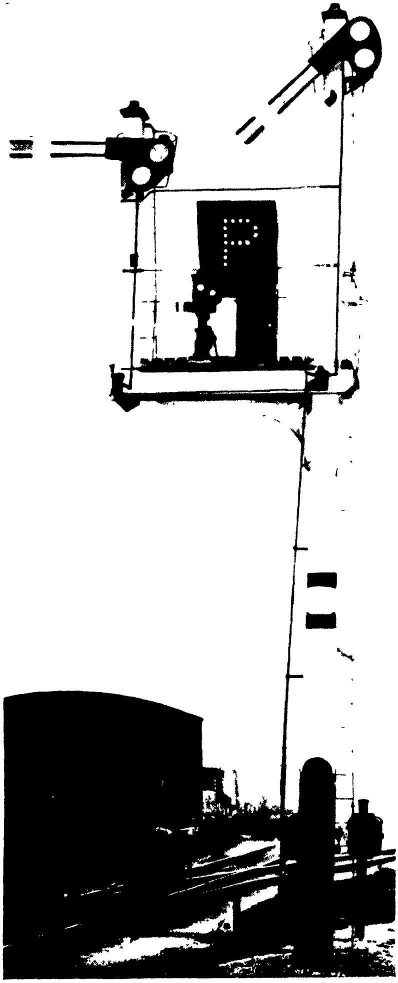
Pl. 162.

"Somersault" signal, L.N.E.R (G.N. Section) (p. 322).



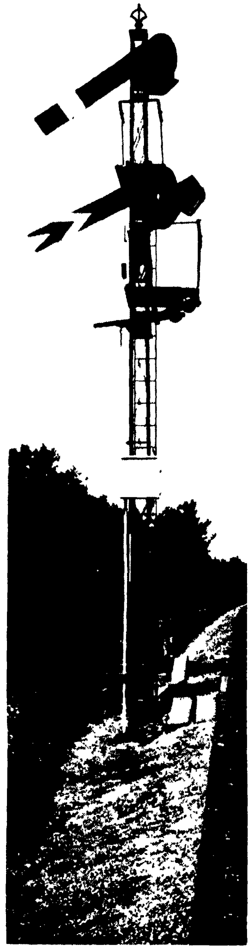
Y 330

Three-position junction signal, London Electric Rlys. (p. 327).



Pl. 163.

Semaphore signal with electrically-operated route-indicator (p. 328).



Y 331

Home and distant signals on the same post (pp. 321,

signal is the electric "banner" (Plate 161); this is not a distant signal, in the ordinary sense, although a driver may pass it when at danger, but electrically repeats the position of the next stop signal ahead, possibly not more than ¼-mile away. The banner itself is a thin strip of metal, painted red, and revolving in a circular case with an opal glass background, which is illuminated from behind at night; the "on" position is horizontal and the "off" vertical.

The latest developments in signalling have been the various "light" systems, in which, both by day and night, electric lamps replace semaphore arms. Previously light signals were confined to the Underground lines, Plate 167 illustrating a type commonly in use, with moving spectacle. But in the recent outdoor installations the lamps themselves have lenses which concentrate a beam of light of great intensity exactly in the direction of the approaching trains, and, being hooded above, are clearly seen from considerable distances even in the brightest sunlight. Separate lamps are required for each indication, whether red, yellow or green. Light signalling systems are usually combined with entirely automatic signalling; that is to say, by suitable electrical connections the trains put their own signals to danger as they pass, and clear the road behind them when they have got within the protection of the next stop signals ahead. Such signalling installations as these are extremely costly to instal, and until now have only been justified when applied to lines carrying very dense traffic, such as certain of the electrically-operated suburban lines round London.

In these cases "three-aspect" signalling is usually employed, corresponding in its working to the three-position semaphore signals already described. There are three lamps, one above another, red, yellow and green in sequence, on each post. The red indication is, of course,

"stop"; the yellow light shows that the line is clear to the next light signal only; the green light indicates that at least two sections ahead are clear. On certain of their busiest electric lines, the Southern Railway have gone even further than this, with "four-aspect" signalling (Plate 168). Here the yellow indication is doubled, the four lights, from the top of the post, being in sequence red, yellow, green and yellow. Red again indicates "stop"; two yellow lights together show a track clear to the next signal only; one yellow light alone proclaims two sections clear ahead; and a green light indicates at least three sections clear. Such signalling as this is of the greatest value to drivers of trains as helping them to regulate their speed to a nicety, so economising in current or steam, avoiding unnecessary applications of brakes, and, above all—the *beau ideal* of railway operation—keeping the traffic on the move.

It should be added, at this point, that there are one or two installations in this country of automatic signalling in which ordinary semaphore arms are employed. Of these the best-known, as well as the most extensive, are those of the Southern Railway, over 23 miles of its four-track Western main line, between Woking and Basingstoke, and the East Coast main line of the L.N.E.R., over 11 miles between Alne and Thirsk, just north of York. In both cases the signals consist of stop signals, carrying under them on the same posts distant signal arms for the next succeeding stop signals. Another installation may be found on the Great Western Railway, whose four-track route between Reading and Didcot is for part of its length equipped with semaphore signals automatically-operated. As in the case of all automatic signalling, the junctions along the routes concerned must be provided with ordinary signal-cabins, staffed by signalmen in the usual way. There is

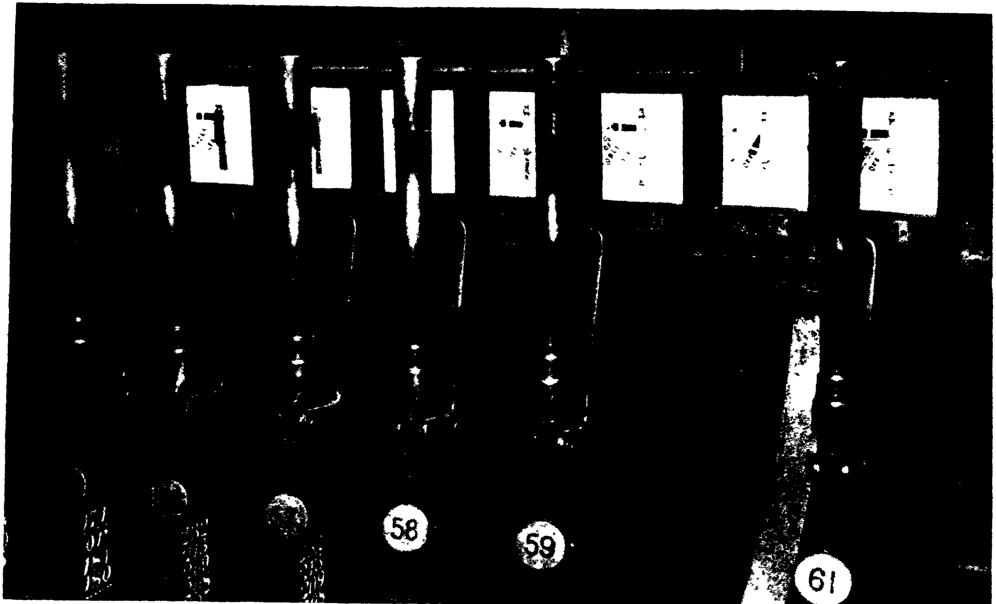
only one automatically-worked junction in the country, and that is on the Mersey Railway of Liverpool, where the trains alternate exactly between two different routes, and automatic electric working presented little difficulty.

At important junctions, where lever movements are frequent, signalmen are in certain cases given power assistance, for the purpose both of reducing the manual labour, and also of expediting their work. This assistance is of various kinds. Electro-mechanical signalling is employed at the L.M.S. St. Enoch Station, Glasgow, the "Brighton" side at Victoria, S.R., and elsewhere; in this the signals are electrically and the switches mechanically operated. Low-pressure pneumatic signalling is used by the L.N.E.R. in the Manchester district; electro-pneumatic, in which switches and signals are worked by pneumatic power under electric control, is the method adopted at Glasgow Station, L.M.S., Newcastle Central, L.N.E.R., Wath Marshalling Sidings, L.N.E.R., and at various other points. The present tendency, however, is rather in the direction of all-electric signalling, in which all the movements are directly effected by electric power. The earliest British installation of this type was at Crewe, on the late L.N.W.R.; it has been followed by Euston to Chalk Farm and at Derby, L.M.S., Snow Hill Station, Birmingham, on the G.W.R., and the extensive plants in the London suburban area of the Southern Railway. The largest British signal-boxes are detailed in Appendix K.

Of these the most remarkable is the new signal-box controlling all lines at London Bridge Station, of which a striking photograph appears in Plate 160; with its 311 levers this is the largest all-electric signal-frame in the world. It displaced four independent frames and cabins previously in use, and has had the effect of cutting down the previous

staff of signalmen at London Bridge, which numbered 50 men and 12 boys, to 16 men and 8 boys, of whom, at the busiest times, 6 men are employed simultaneously to work signals and instruments, and 4 boys to record all train movements. Plate 175 illustrates part of the complex electrical relay mechanism below the floor of this cabin. The electric motor-gear of a switch, with the cover removed, is shown in Plate 170, and Plate 169 similarly exposes the interesting details of a motor operating a semaphore signal. It should be added here that the advantages of remote control offered by electricity are being utilised increasingly, both to break up long sections between signal-boxes by the installation of intermediate signals electrically operated by the nearest adjacent box, or, alternatively, to abolish intermediate signal-cabins, at locations where no connections exist and no shunting movements have to be made, similarly controlling their signals electrically, with the additional safeguard afforded by track circuit, from adjacent boxes. The chief objection to power signalling, as to automatic signalling, is the cost, but, as just explained, it renders possible considerable economies in working. A colour representation of a junction box of the manual type appears in Plate 166.

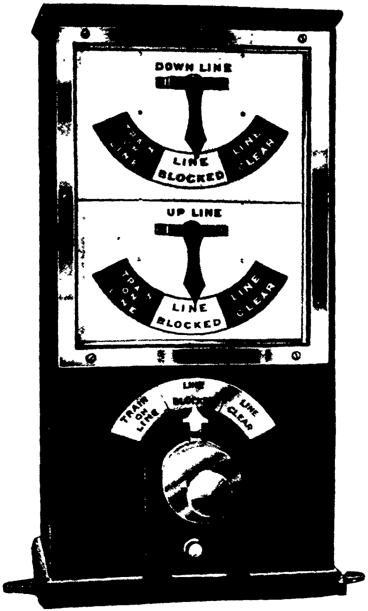
In describing the equipment of a signal-box, it is best to consider a fairly simple example, such as a cabin controlling a double line of railway, with a cross-over road and a few sidings, at some country station. The most prominent feature of the box (Plate 164), on the side facing the track, is the long row of operating levers. Of these the shafts are painted in various colours, according to the signals that they control. Distant signal levers are painted green, or, on lines which paint their distant signal-arms yellow, the latter is the colour adopted; stop signals and siding or ground signals have red levers; black is the colour for switch

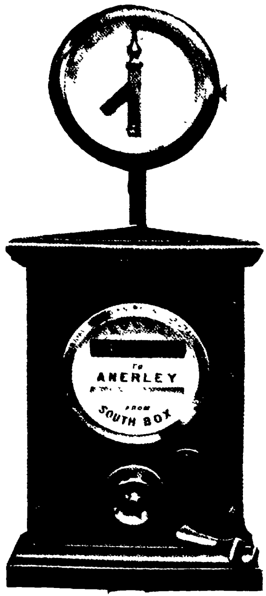


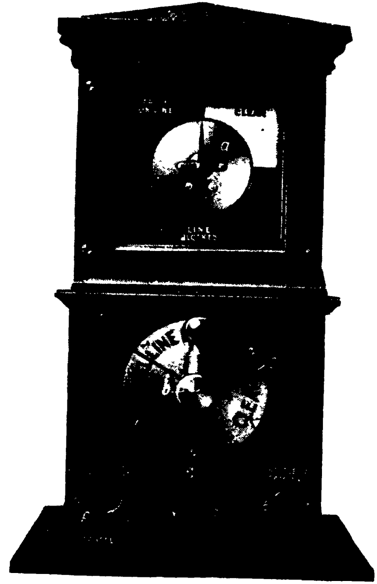
Pl. 164. | Y 334.

Levers in Signal-Cabin (pp. 164, 326. 334, 345).

Each lever bears on the front a number corresponding to the number of the signal, switch or bar on the lay-out [illegible] painted on the side of the shaft. Electric repeaters on shelf behind levers.







Pl. 165.

3-position Block Instrument for up and down lines.

Sykes Lock-and-Block Instrument.

3-position Block Instrument for one line only.

Electric Signalling Instruments (p. 343).

levers ; blue for locking bar levers, referred to presently ; and " spare " levers—that is, levers provided for possible future extensions of trackage—are painted white. The outermost levers in the frame are usually those of the distant signals, arranged at the respective ends of the frame from which direction will approach the trains whose movements they govern. Next to the distant lever comes that of the outer home, if any ; then the home and starter, and then the advanced starter, should the latter be provided. In the middle of the frame, between the levers of the main line signals, are those of the switches and the siding signals, as well as the " spares."

Only the upper part of the frame is seen. Under the floor of the cabin is the essential " locking table " (Plate 172), integral with the lower part of the frame. In early railway history the importance was recognized of mechanically preventing a signalman from giving conflicting signals, which might render collisions possible, and a junction at Bricklayers' Arms, near what was then the London terminal of the South Eastern Railway, saw the first attempt at railway signal interlocking on record. In 1856 the Saxby system of interlocking was patented. It is, first of all, the interlocking which locks the lever of the distant signal (Plate 163) in the " on " position, until the levers of the home and starting signals have been pulled off, freeing the distant signal lever. If any shunting operations are being performed in the station yard, affecting the main lines, the main line stop signals—or such of them as might allow of a collision if they were pulled off before the shunting is complete—are all locked in position. The purpose of the locking is to prevent the possibility of any conflicting train movements, and in the Government inspection which precedes the bringing into use of any new signal cabin, it is the locking which forms the subject of the most stringent tests.

At junctions, of course, the signals are interlocked in such a way as to prevent any two trains being signalled to converge, or, at a double junction, a train travelling in one direction to cross the path of another in the opposite direction, and the switches are correspondingly locked with the signals. The locking of a power-operated signal-frame is seen in Plate 141.

Another form of locking is that which is used to prevent a signalman from moving a switch during the passage of a train over it. With the lengthy space between the bogies of modern coaching stock, it would be comparatively easy to move a switch between any two pairs of wheels, and so to split a train, and such a contingency must therefore be guarded against. The general method is to employ a light steel bar (Plate 171), about 40 ft. long, carried on a row of swinging arms which are pivoted at the lower ends to one of the rails of the track, closely adjacent to the switch, or actually to the tongue of the switch itself. When the arms are at the two limits of their travel, the bar lies below the surface of the rail, but in the middle of their swing they lift the bar above the rail level. Before the switch can be moved, it must be "unlocked," an operation which the signalman performs by pulling over the locking-bar and shifting the lock, for both of which operations one independent lever suffices. Clearly he cannot do so if a train is passing over the switch, as the bar, in rising, would foul the wheels. When the signalman has moved the switch, he must replace the locking bar lever in the frame, so relocking the switch, or the locking-frame in the box will not permit him to pull off the appropriate signals. Another type of "bar" is sometimes used, called a "fouling bar," but this has a different function. A fouling bar is balanced in such a way that its normal position is up, foul of the wheels, but it is depressed when a train is standing on or passing

Pl. 166.

Interior of Manua

Signalling instruments on shelves above levers; diagram of lay-out above ins

Y and Z.

Signal Cabin (p. 334)
right-hand side: telephones to right and train register on desk to left at back of

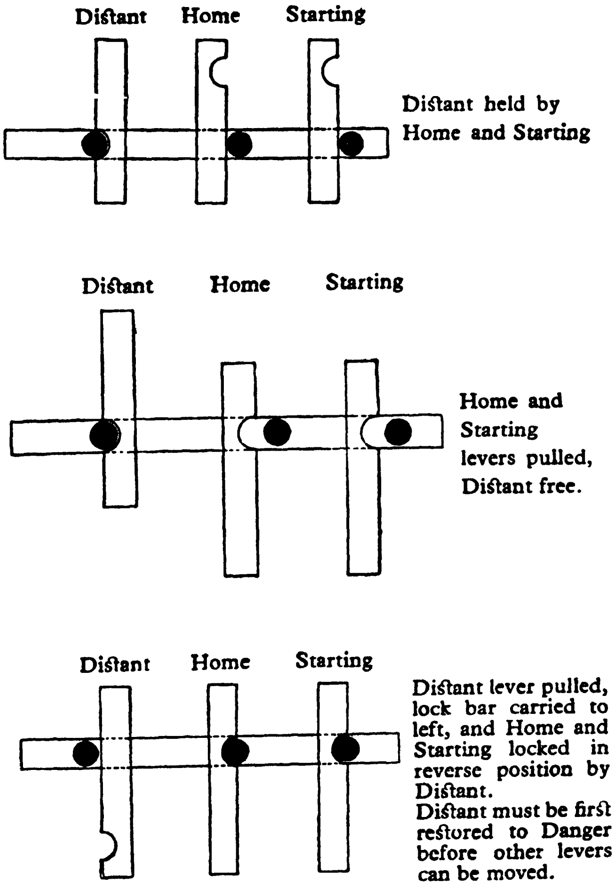
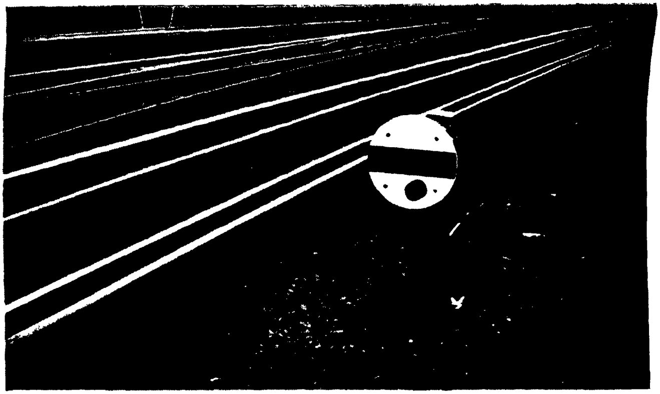


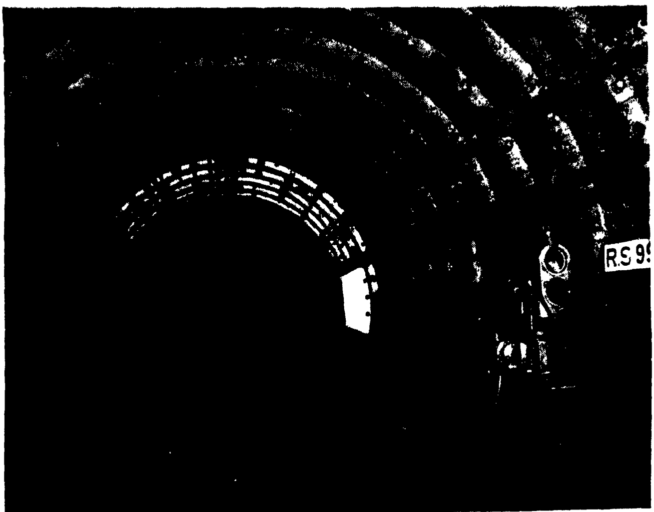
Fig. 24.—Diagram showing how distant signal lever is locked with home and starting signal levers

over it. The purpose of bars of this type, which are used principally in station platforms or at other points where trains or engines may stand, out of sight of the signalman, is electrically to advertise their presence in the signal-box. It should be mentioned at this point that the movement of switches in this country is usually effected by rodding, in order to allow of the necessary operation of pushing as well as pulling. In other countries, including British Colonies, however, increasing use is being made of "double-wire" signalling installations, in which each switch or signal is moved to and fro by two stranded wires. A typical double-wire signal-frame is shown in Plate 172.

Above the row of levers in the signal-cabin is a shelf on which stand the all-important electric signalling instruments. At a double-line box these are usually in two pairs, one pair for the down line and one for the up. One of each pair communicates with the nearest signal-box in the up direction, and the other one of each pair with the nearest box in the opposite direction. The instruments are designed to exhibit to the signalman exact indications as to whether or not the sections between him and the adjacent boxes are "blocked"—that is, that no trains have been accepted or are in course of transit through them—or whether he has "accepted" a train, or, yet further, whether a train is actually passing through the block. There are thus, on the majority of instruments, three visual indications, electrically given by moving needles, or lettered slides moving in openings on the face of the instrument:—"Line Blocked," "Line Clear" (a train having been accepted) and "Train on Line." The various messages relating to the movement of the trains are exchanged by means of a code of bell signals, carried out on single-stroke electric bells, of which the following are some of the more important varieties:—



Ground-disc signal, Metropolitan Railway (p 330.)



Pl. 167. Z 338.

Tube Tunnel-signal, London Electric Railways (p 331)

Pl. 168 Z 339.

Four-Aspect Colour-light Signals, Charing Cross Station, Southern Railway (pp. 330, 332).

	No. of Beats.
Is Line Clear for Express Passenger Train ?	4 consecutively
Is Line Clear for Ordinary Passenger Train ?	3 pause 1
Is Line Clear for Fish, Meat, Fruit, Horse, Cattle or Perishable Train composed of coaching stock ? - - - - - - -	5 consecutively
Is Line Clear for Empty Coaching Stock Train ? - - - - - - - - -	2 pause 2 pause 1
Is Line Clear for Perishable Train composed of goods stock, or Express Goods Train, Class "A" ? - - - - - - -	3 pause 2
Is Line Clear for Express Goods Train, Class "B" ? - - - - - - -	1 pause 4
Is Line Clear for Light Engine, or Engines coupled together, or Engine and Brake ?	2 pause 3
Is Line Clear for Through Goods, Mineral or Ballast Train ? - - - - -	4 pause 1
Is Line Clear for Ordinary Goods or Mineral Train stopping at intermediate stations ?	3 consecutively
Is Line Clear for Ballast Train requiring to stop in section ? - - - - -	1 pause 2 pause 2
Is Line Clear for Platelayer's Trolley requiring to pass through Tunnel ? - -	2 pause 1 pause 2
Train entering Section - - - - - -	2 consecutively
Bank Engine on rear of Train - - -	2 pause 2
Train out of Section - - - - - -	2 pause 1
Obstruction Danger (x) - - - - - -	6 consecutively
Stop and Examine Train (x) - - -	7 consecutively
Train Passed without Tail Lamp (x) - -	9 consecutively to box in advance 4 pause 5 to box in rear.
Vehicles Running Away on Wrong Line (x)	2 pause 5 pause 5
Vehicles Running Away on Right Line (x)	4 pause 5 pause 5
Call Attention signal which must precede all emergency signals marked (x) above -	2 pause 2 pause 2 pause 2
Shunt Train for following Train to pass -	1 pause 5 pause 5
Section Clear but Station or Junction Blocked (enabling train to proceed after driver has been verbally cautioned) -	3 pause 5 pause 5
Opening of Signal-Box - - - - - -	5 pause 5 pause 5
Testing of Bells - - - - - - -	16 consecutively
Closing of Signal Box - - - - -	7 pause 5 pause 5

It will be seen from this list how varied are the train movements for which provision must be made in the signalling, with a view to perfectly safe working, even down to the presence of the humble platelayer's lorry in a tunnel. The list given above is not complete; and at junctions in particular these bell signals are supplemented by various others connected with the routing of the trains.

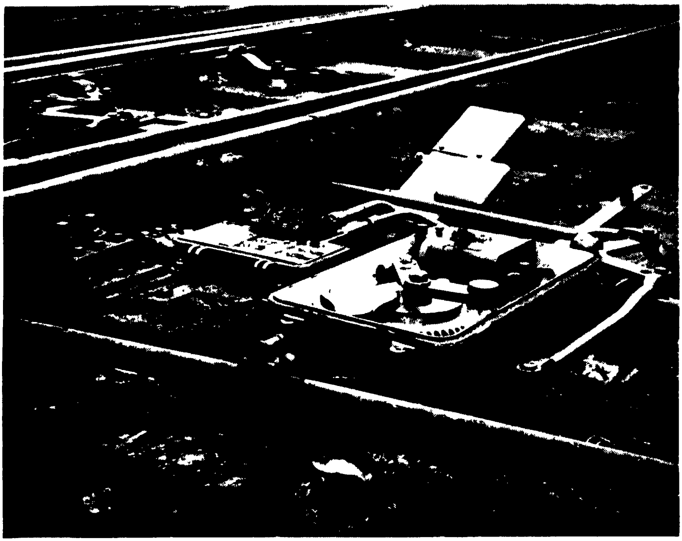
Assuming a sequence of signal-boxes, "X," "Y" and "Z," and the approach of an express from "X," the course of operations in the signal-box would be roughly as follows, if we were in Box "Y." The first intimation would be a single, or "Call attention" beat on the bell from "X's" cabin, which would be acknowledged from our cabin by one beat on the plunger or tapper under the two instruments relating to the "XY" section. Next would follow four beats in succession—"Is Line Clear for Express Passenger Train?"—on the "X" bell, similarly acknowledged. Provided that the line was clear, our signalman would then move the lever under his "X" to "Y" down line instrument in such a way as to shift the needle on both his and "X's" instrument from "Line Blocked" to "Line Clear." On the plunger under the "YZ" pair of instruments our signalman would then "Call Attention" of "Z" by one beat, and after acknowledgment, heard on the bell from "Z's" box, would repeat the four beats, and wait, not only for the acknowledgment, but also to see the needle or slide on his "Y" to "Z" down line instrument move to "Line Clear." Then he is in a position to move his down line signals, first pulling off the stop signals and last the distant signal, noting especially by the electric repeater that the arm of the latter has duly fallen.

Shortly afterwards two beats are heard on "X's" bell, indicating that the express is now entering the section; these are repeated by the plunger or tapper, and our signal-

man again moves the operating lever of his down line " X " to " Y " instrument, changing the indication in both his and " X's " box to " Train on Line." Soon the express bears into view ; as it passes, our signalman has first to bell signal " Train entering Section " to " Z," and watch for the movement of the " Y " to " Z " instrument needle to the corresponding position ; then to put all his down line signals to danger, beginning with the distant, and after that the stop signals ; and last of all to ring " two beats—pause—one beat " back to " X," indicating " Train out of Section." At the same time he resets his " XY " down line instrument to " Line Blocked," thus indicating to " X " that the latter is at liberty to call up the next train. In a few moments " two—pause—one " is heard on " Z's " bell, and the needle of the " YZ " down line instrument is seen to return to " Line Blocked," so ending the whole sequence of operations. On the Great Western Railway the down and up line indications are often combined in one instrument, so that in an ordinary double-line box there are, instead of four, two instruments only, one relating to the nearest box in one direction, and the other to the box in the opposite direction.

In the vicinity of large stations it is not always possible to work strictly to block regulations, without causing undue delay to traffic, and different varieties of " permissive block " working are therefore put into operation, the chief advantage of which is that—with appropriate safeguards—one train may be admitted to the rear of a platform at the front end of which another train is standing, and so on. The same principle is adopted in connection with what are called " reception " lines for freight trains. Along main lines of railway, where it is necessary to provide, at fairly close intervals, sidings where freight trains may be stowed temporarily, to allow passenger or faster freight trains to pass, the refuge siding has now been largely supplanted by

Automatic Train-Stop, London Electric Railways (p. 342).



Pl. 170. Z 343.

Electric Point-motor (with cover removed) Southern Railway (p. 334).

train, when required, within a given distance, is practically impossible of invention. The most that has been done in this direction on steam-worked lines has been the installation of cab-signalling. Equipment of this character can be found over the Great Western main line between Paddington and Reading, and over the East Coast main line of the L.N.E.R. between York and Newcastle; raised ramps between the rails, working in conjunction with the signals, actuate an electric bell in the driver's cab (clearly seen on the right-hand side of Plate 86, ref. 17 of Fig. 17) of every engine so fitted, giving him an audible indication that he is passing a signal at danger. The value of such equipment in foggy weather can be readily appreciated; here again cost is the chief obstacle to its installation on a larger scale.

There are, however, various ways in which a signalman is protected from the disastrous possibilities of momentary forgetfulness. One is the system of signalling known as Sykes's "lock-and-block"; this is a species of compromise between manual and automatic signalling, wherein the trains, by electrical means, have a share in their own protection. When a signalman "offers" a train to the next box ahead of him, by the usual code of bell signals, the signalman in the latter, "accepting" the train by means of a special plunger on his instrument (Plate 165), not only causes the movable slide to change from "Line Blocked" to "Line Clear," but also frees a lock on the starting signal lever of the signalman who offered the train. Not until then is the latter able to pull off his starter. Then, when the first signalman rings "Train on Line" to the second, the latter drops a small swinging hook on to the spindle of his plunger, which both changes the indication on the face of the instrument from "Line Clear" to "Train on Line," and also prevents him from plunging to accept a second train until the first has cleared his section. The next stage of the

operation is that, by means of a back-lock, the second signalman is unable to replace his starting signal lever to danger until the train itself has passed over an electrical contact well ahead of the signal concerned. When he has returned his starter to the " on " position, he " unhooks " the plunger of the signalling instrument, and the ingenious sequence of operations starts again. " Lock-and-block " signalling is installed over practically all the London suburban area of the Great Eastern section of the L.N.E.R., with its dense traffic, and over the Brighton or Central Division of the Southern, as well as in certain other parts of the country.

A somewhat simpler form of protection is that known as " Track Circuit," which is more local in its application; that is to say, it does not operate, generally speaking, between box and box, but only over the lines controlled by any one box. The two rails of each running line are carefully insulated in such a way as to form a complete circuit, and a good flow of electric current from each rail to the next is ensured by " bonding " the rails together at the rail-joints, which is an immediate external indication to the observer that track circuit is in use. Electrical connections are then made in such a way that if any train, engine, or vehicle is running over, or standing on, the electrified length of track, a shorter path is found by the current through the wheels and axles, from one rail to the other; this short-circuiting has the effect of breaking an auxiliary circuit, which in its turn imposes a lock on the home signal of the section concerned, so that the signalman cannot pull the latter off until the line has been cleared. Generally, also, both visual and audible indications are given in the signal-box that the section is occupied.

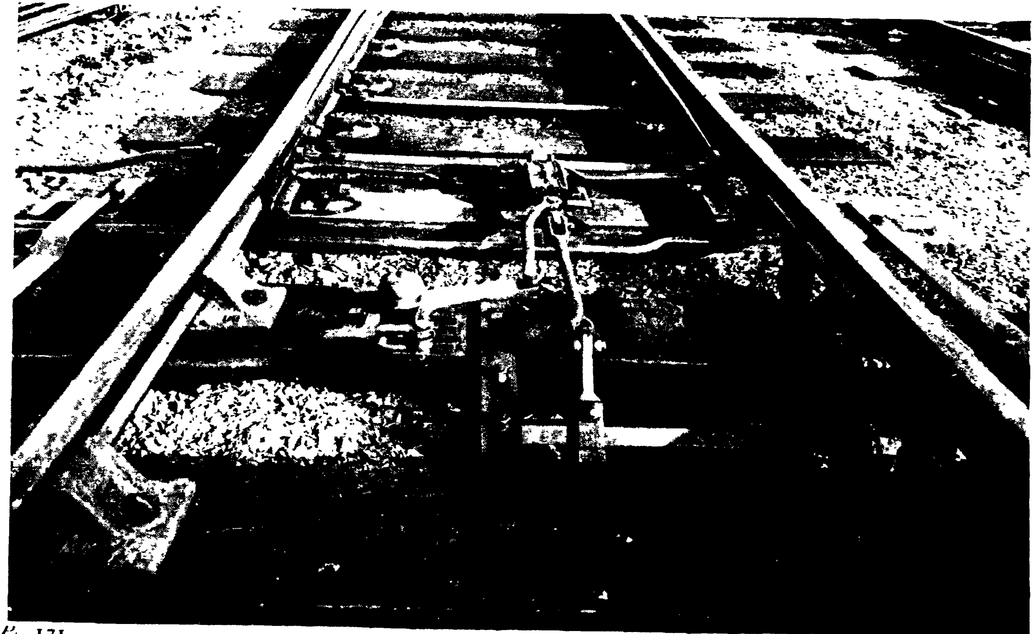
One advantage of track circuit is that the well known " Rule 55 (*a*) " of the railway rule-book, which requires the fireman of an engine to proceed to the signal-box, if his

train is held up for any length of time at a starting or advanced starting signal—again, to aid the signalman's recollection of the fact that his section is occupied—need not be obeyed where track circuit is in use, as the train advertises its own presence in the box, in the way just described. A special indication appears on such signals, usually in the form of a white diamond on the post, below the arm, but elsewhere as a notice, illuminated at night, "Track Indicator in Box." In certain other cases telephones are provided from the starting signal to the signal-box, for the same reason, an indicator in the shape of a white ring being fixed to the post under the arm concerned. Track circuit has proved itself of such value as a safeguard that it is now very widely used, a number of independent track circuits often being installed in connection with any one signal-box.

Little need be said concerning the signalling operations connected with shunting. The lay-out of the area controlled by each box is clearly shown on a large framed diagram, hung immediately in the signalman's view above or between the instruments; on this every switch, locking-bar and signal has its own distinctive number, the same numbers being carried in a prominent position by the corresponding levers. Under the diagram is the "Table of Locking," showing the exact working of the locking-frame; and on the shaft of every lever, or on a plate fixed to the front of the shaft below the handle, are painted the numbers (Plate 164) of the other levers which must be pulled over—or, alternatively, put back—in the frame before it can be released. In power-operated cabins it is now often the custom to provide an illuminated lay-out diagram, each track being marked out with small electric lights, which are extinguished when any section of the track is occupied by a train. The signalman is thus apprised of the exact occupancy or freedom of

every track under his control. These illuminated diagrams are clearly visible in Plates 141 and 160.

The possibility of freight trains over-running signals in sidings, and more especially of over-running exits from sidings on to main lines, is guarded against by the laying in of short trap sidings, or dead-ends, into which each siding leads directly until the cross-over from siding to main line has been duly set. Another possible danger which must be guarded against is that of part of a train breaking away when it is running or shunting. With passenger trains the risk is but small, as the use of the continuous brake ensures that both halves of a train thus breaking in two would come instantly to rest by the severance of the brake-pipe. But a broken coupling on a freight train may cause the rear part to run away, especially down a steeply falling gradient, with considerable danger to any train following. To reduce this danger to a minimum it is therefore customary to lay in, on inclines, spring switches which lie normally open; these switches are known variously as "catch-points," "throw-off switches" and "traps." They are trailing to the direction of running; as a train proceeding normally passes over the catch-point, the latter springs to the closed position, but if any vehicles were to run backwards down the incline—known in railway signalling as "Train running away on wrong line," the catch-points would derail them before they did any further mischief. The case of vehicles running away on the right line, though a much more unlikely happening (as most breakaways are from the back of running or starting trains), is almost impossible to guard against, as obviously it is not practicable to arrange catch-points facing the normal direction of running. To minimize the possibility of vehicles running away during the course of shunting, it is laid down by statute that the steepness of gradient in station yards shall

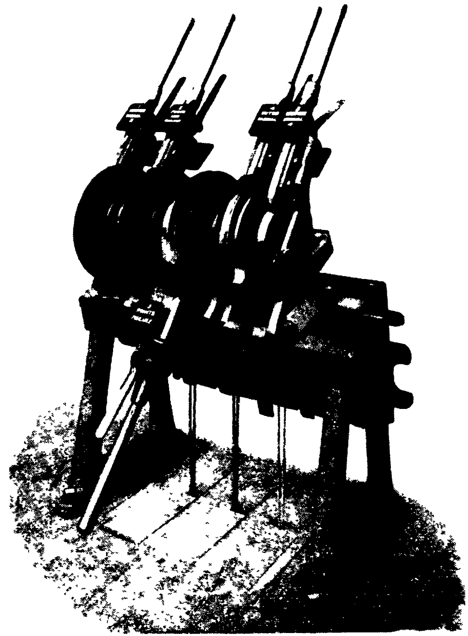


Pl. 171. ∠ 340.

Switch with Facing-Point Locking-Bar, G.W.R. (p. 336).

Locking-bar to right; lock in centre, connected to the two switch-tongues.

F. 172.
Ordinary Frame, showing locking-table at base (p 335).



Z 347.
Double-Wire Frame (p 338).

not exceed 1 in 260, which has been proved flat enough to prevent any tendency on the part of vehicles to get in motion on their own account.

Attention must now be directed briefly to the problem of safely working single lines of railway—that is, routes over which trains are worked in both directions on one line of rails. The earliest method of ensuring that no two trains should meet in a head-on collision on a single line was to provide a token, which had to be in the possession of a driver before he entered the section concerned from either end. This method is still possible on certain country branches carrying but a sparse traffic, where safety is assured by permitting only one engine in steam to be on the branch at any one time. But with busier branches, and still more with certain main lines of railway which for considerable parts of their length are single, the method of using one token only is ruled out by the fact that two or more trains may require to run in one direction, over the single line, before any train runs in the opposite direction, and so is able to bring the token back to the starting-point.

The difficulty has been got over by combining with the single line signalling instruments a small store of tokens (Plate 173). In principle, if the two instruments at the opposite ends of a single-line stretch can store between them, say, twenty tokens, only one token can be out and in use at any one time. That is to say, if a driver carries one token from one end of the single line to the other, that token must be returned to the instrument at the far end of the same stretch before another token can be withdrawn from the first instrument for the use of the next succeeding train, or, alternatively, from the second instrument for the use of a train in the opposite direction. Thus provision is made for a sequence of trains up to a dozen or more, if necessary, in one direction, without any in the opposite

direction, and yet without infringement of the safe principle that only one token is ever in use at one time.

The tokens themselves are of several types; the older "train staff" is usually a small metal token, enclosed in a pouch to which is attached a looped metal handle, for convenience in exchanging the tokens at intermediate passing-places on a single line, where the train passes from one single-line section on to the next. The electric train-staff is carried in an instrument of different design (Plate 173) and is like a bar in shape. The exchanging to which reference has been made was at one time—and on many country branches still is—done entirely by hand, the speed of the trains having to be reduced to about 15 m.p.h. for the purpose. Various devices have now been introduced, however, to expedite the operation, and on main lines like the Highland Division of the L.M.S., or the Somerset and Dorset or Midland and Great Northern Joint Lines, where the passing-places and the locomotives are fitted for entirely automatic exchange, and the passing-loops are laid out admirably for high speeds, it is nothing unusual to exchange the tokens at speeds up to sixty miles an hour.

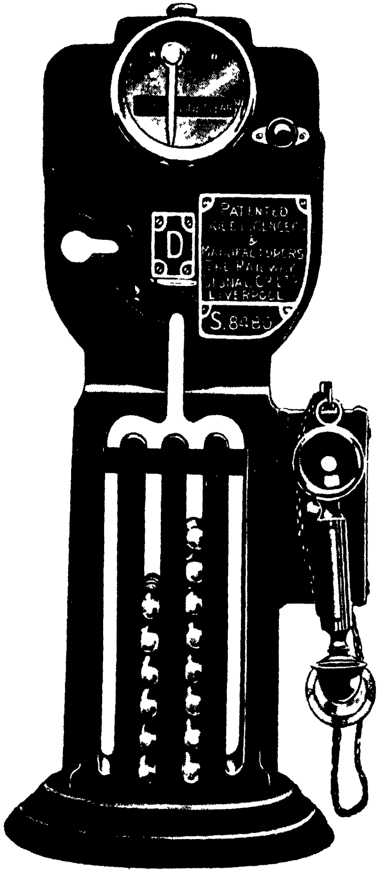
Another description of single-line working that finds a limited use is known as "reversible" working. The best known example of this practice is found on the Central Division of the Southern Railway, where for a short distance, through Peckham Rye, on the south side of London, three tracks are in use, one for down trains, one for up trains, and the centre one reversible. During the morning period of peak loading, the reversible centre road is used for up traffic, but during the afternoon and evening its use is reversed, and it becomes a down line. Special signalling and signal-box equipment are needed in regard to the reversal, to ensure that only one direction of working is in use at any one time.

Mention has not yet been made of the way in which signalmen, in using the code of bell-signalling, identify the various trains. In Great Britain, as all the railways are fenced and the likelihood of such obstructions on the line, as, say, straying cattle, is very remote, there is no need for engine headlights of the great size and power of those employed, for instance, in the Colonies (Plate 145) or in America (Plate 19), nor of the " cowcatchers " used in those countries. But the number and arrangements of head-lamps carried by an engine in this country are used as a means of describing the character of the train behind the engine. Lighted headlamps are used by night, and un-lighted headlamps—painted white on the L.N.E.R., so that they may be seen from a greater distance—give the necessary indications in the daytime. Of these the most familiar is the pair of headlights—one over each buffer—carried by express passenger trains (Plate 123); other indications are shown in the diagram (fig. 25) on page 351.

Certain railways—the Southern in particular—have such a complexity of routing that the engine headlights have to be used, instead, to indicate the routes over which trains are to travel. In addition to the usual lamp positions—at the centre and the two ends of the buffer-beam and at the base of the chimney—the Western Division engines of the Southern have lamp-irons on either side of the smoke-box. A common main line head-code over this section of the Southern consists of two lamps in the position last-mentioned, forming a triangle with one at the base of the chimney, which indicates a train between London, South ampton and Bournemouth. On the L.N.E.R., white lamps have to be supplemented by blue lamps, in the London suburban area, for the same purpose of indicating the routes to be followed by trains. On the Southern Railway and the Great Eastern section of the L.N.E.R., also,

identification of trains in the daytime is greatly simplified by the substitution for the lamps of round sheet metal discs, which can be seen clearly at a great distance. Another method of route-indicating is that adopted by the Caledonian and Glasgow and South Western sections of the L.M.S., where the engines, in addition to carrying the national code of headlights, are provided with route indicators. These consist of two white arms, which can be set at any position, like the hands of a clock, different " times " indicating the various routes ; the indicator is then mounted on a lamp-iron, where it can be seen easily, usually at the base of the engine chimney. The only defect of this method is that it offers no means of indicating routes at night.

The bane of railway signalling is fog ; thickly falling snow, which in this country is fortunately of rare occurrence, is nearly as objectionable. In both cases there is serious interference with the visibility of the signals, varying with the density of the fog or the snow, and steps must be taken to supplement the ordinary signalling with signalling of an audible character. As we have already seen, some railways have provided limited lengths of their line with audible cab-signalling apparatus, which has its maximum value at times of fog, but elsewhere—except on electric lines, where the even more perfect protection of train-stopping apparatus is in use—it becomes necessary to resort to fog-signals, or detonators. The duty devolves on the signalmen of deciding when the fog is sufficiently dense to call out the fog signalmen, who are, for the most part, the men concerned with the maintenance of the track, unable to pursue their ordinary work in such conditions. Their business is to see that, at every signal which is " fogged " for, explosive detonators are placed on the rails throughout the time that the signal for which they are responsible is at danger, but are removed as soon as the signal is pulled off.



Pl. 173. Z 350.

Electric Train-Staff Instrument (p. 317).

The supply of staves is seen in the two slots at the lower part of the instrument.

Pl. 174.

Charging the Magazine with Detonators.

Z 351.

Working the machine: detonator-placing levers in front, and repeating signals behind.

[illegible] Machines for Fog Signalling (p. 351.)

Huts are provided adjacent to each signal, and the fogman, who may have to remain at his post for considerable periods together, makes himself as comfortable as he can beside a blazing fire; arrangements are made for his meals

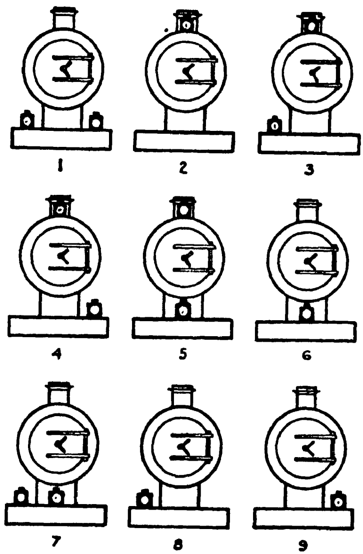


FIG. 25.—BRITISH NATIONAL CODE OF ENGINE HEADLAMPS.

1. Express Passenger Train, Breakdown Train going to clear line, or Light Engine going to assist disabled train.
2. Ordinary Passenger Train, or Breakdown Train not going to clear line.
3. Empty Coaching Stock Train.
   Express Fish, Meat, Fruit or other train carrying "Perishable" traffic, or Horse or Cattle Train, composed of coaching vehicles fitted with the continuous brake.
4. Fish, Meat or Fruit Train or Express Cattle or Express Freight Train composed of Freight stock, Class "A" (speed, 30 miles per hour).
5. Express Cattle or Express Freight Train, Class "B" (speed 25 miles per hour).
6. Light Engine or Engines, or Engine with Brake-van.
7. Through Freight or Ballast Train, not booked to make intermediate stops, Class "C" (speed 20 miles per hour).
8. Through Freight Train, making intermediate stops.
9. Ordinary Freight Train, calling at intermediate stations.

to be brought to him. In order to reduce to a minimum the hazards of "fogging," many devices have been brought into use, including various types of "detonator-placer." This appliance (Plate 174), worked by a lever outside the fog-hut, enables the fogman to place detonators on and remove them from lines other than the one nearest to him, without having to cross any track for the purpose, so that one man can safely "fog" for two or more tracks at one time. Each placing machine is provided with a reservoir of detonators (Fig. 174), which is sufficient for several hours of working. In order that the fogman may know accurately the position of every signal for which he is responsible, diminutive signals are erected in front of his hut, which repeat exactly the movements of the full-size signals.

To the uninitiated, the work of railway signalling sounds extremely complicated, but except in the busiest boxes it is soon mastered. In the case of signal-boxes controlling four or more tracks, or important junction or terminal station boxes, however, the signalling does become a highly skilled operation. In addition to a row of levers of great length, interlocked with the utmost complexity, there may be a whole series of signalling instruments, each with its own distinctive bell, not to mention a number of telephones, on different circuits, sounding a variety of bells or buzzers, all to be distinguished from one another. The passage of every train, and the time at which each bell signal relating to it was exchanged with the neighbouring boxes, must be entered in the train register, in case the figures should be required for future reference. In busy boxes boys are employed to enter up these figures. Many of the more important boxes have to be manned by two or more men, each responsible for a certain definite section of the lever frame, and it is of interest to note that the method of payment for work in

these difficult boxes is usually based on the average number of lever movements made per day, which is a rough indication of the amount of work and of responsibility to be undertaken. Railway signalling is, indeed, a very costly business. Some six millions sterling are paid out annually by British railways as wages to signalmen, and another two millions go in maintenance of signalling equipment, helping to make British railway travel, as it most certainly is, safer than that of any other country in the world.

CHAPTER XIX

Some Other Railway Activities

THERE are many activities of the railway far removed from its primary concern of carrying passengers and freight over railway tracks. A description of all these "by-products" of railroading would probably fill another book equal in size to the present volume, and we must, therefore, confine ourselves to some of the more important only. For example, of road vehicles British railways own between them some 325 for passenger traffic and 33,600 for parcels and freight traffic; and now that the desired Parliamentary powers have been obtained for a more extensive use of public roads by the railway companies, these figures are likely to be largely increased. The care of the large number of horses used in connection with van delivery and station shunting work is in itself no light task. Many of the canals in the country are the property of the railways, which are charged with their working and upkeep.

But there are three subsidiary operations which, on account of their magnitude, demand special attention. They are the steamship services run by the railways, the docks and harbours which are railway-owned, and the immense business of catering in railway hotels, refreshment rooms and restaurant cars. Some of the leading figures connected with all three are worthy of remark. Steamers owned by British railways total in number 179, with a gross tonnage of 175,000; between them they work 26 different passenger and 25 freight routes. Of docks and harbours

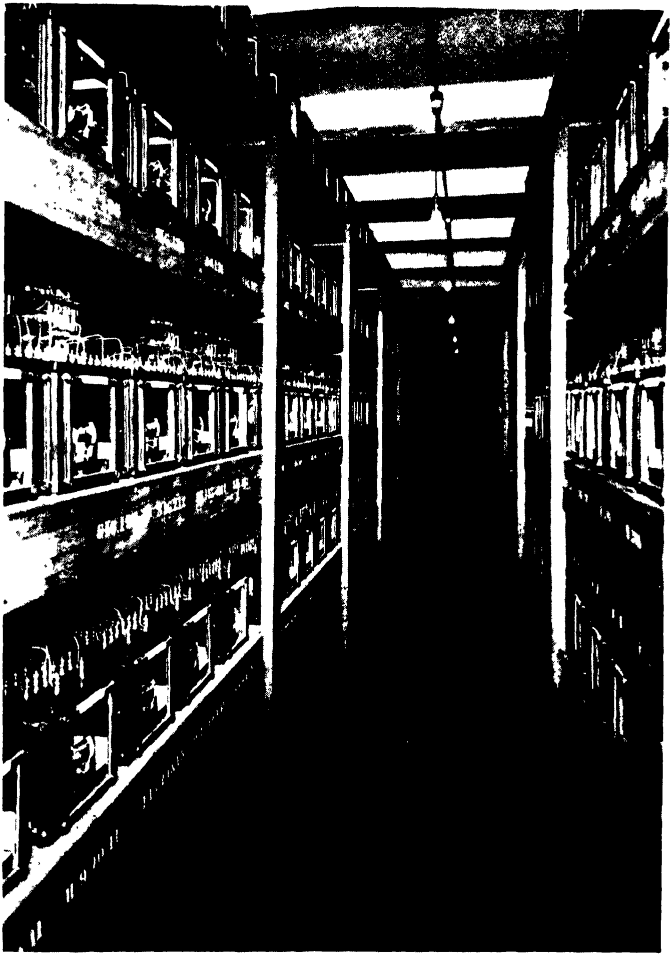
British railways are the proprietors of 168, with a total water area of 2,459 acres and a length of quayage totalling 104 miles. During 1925 the gross tonnage of steamships entering railway docks was 60,200,000 and the aggregate amount of imports and exports there dealt with amounted respectively to 18,300,000 and 72,000,000 tons. The Great Western Railway, with the vast dock accommodation at Newport, Cardiff, Swansea and elsewhere in South Wales, taken over in the grouping from the various Welsh lines laid to bring coal from the mountain valleys to the sea for shipment, now claims to own the largest group of docks in the world. Similarly, the London, Midland and Scottish Railway claims the premier position in the world as regards hotel ownership; and it is certain that British railways, owning 83 hotels between them, control by far the largest group of hotels in the world.

The business of restaurant car catering has made enormous strides in Great Britain during the past few years. In the summer of 1928 no less than 724 trains ran daily, within the confines of these islands, including in their formations either restaurant or Pullman cars, in either of which meals or light refreshments could be obtained. In addition to these there were many duplicate and excursion trains with restaurant cars attached, so that at week-ends, in particular, these figures were greatly exceeded. It is estimated that in 1925 the number of meals served on British passenger trains was 7,600,000, and that the amount of food thus consumed in the trains reached the handsome total of 965 tons of meat, 848 tons of bread and 779 tons of fish. British railways in all cases carry out their own restaurant car catering, except on the Western Division of the Southern Railway, where the work is entrusted to a private firm, and on the Pullman cars. It is the general practice in Great Britain, as we have seen in a previous

chapter, for the restaurant car or cars to form part of the train formation, and, in many cases, to be available to passengers as seating accommodation ; in other countries, where journeys are often very lengthy, it is rather more general to attach the car, as a kind of travelling restaurant, to the train for the duration of one or more meals, and then to detach it in order that it may serve the next meal of the day on a later train or a train travelling in the opposite direction. The idea is to save unprofitable haulage of the cars. The Transcontinental Railway of Australia enjoys the distinction of being the only railway in the world to include the price of meals throughout the journey in its ordinary tickets.

Railway hotels are amongst the finest that this country has to offer. The practice of hotel-keeping by railways is not so widespread in other countries as it is in our own, but here the best hotels in many provincial cities and towns are acknowledged to be those maintained by the railways. Such a palace as the hotel in the Highlands built by the late Caledonian Railway at Gleneagles, between Stirling and Perth, is probably unrivalled in this country for its luxurious equipment, and the Midland Adelphi Hotel at Liverpool is but little behind. These are both numbered among the 34 hotels owned and worked by the L.M.S. Railway.

Refreshment room business is closely allied with that of the hotels and the restaurant cars. Gone are the days in which the antiquity of the railway refreshment room bun or sandwich was a never-failing topic for the humorist. The variety and the quality of the food and drink now obtainable is beyond reproach; and the larger station refreshment rooms, where hot *table d'hôte* meals are served daily, become favourite places of resort at meal times to many other than passengers. It is of interest, in this connection, to note that much of the provisioning of hotels, refreshment-rooms



Pl. 175. 2 A 356

The Relay Room of the All-Electric Signal Cabin at London Bridge Station, Southern Railway (p. 334).

Pl. 176 2 A 357.

A Railway-made British Port -Parkeston Quay, Harwich, L.N.E.R. (p. 357).

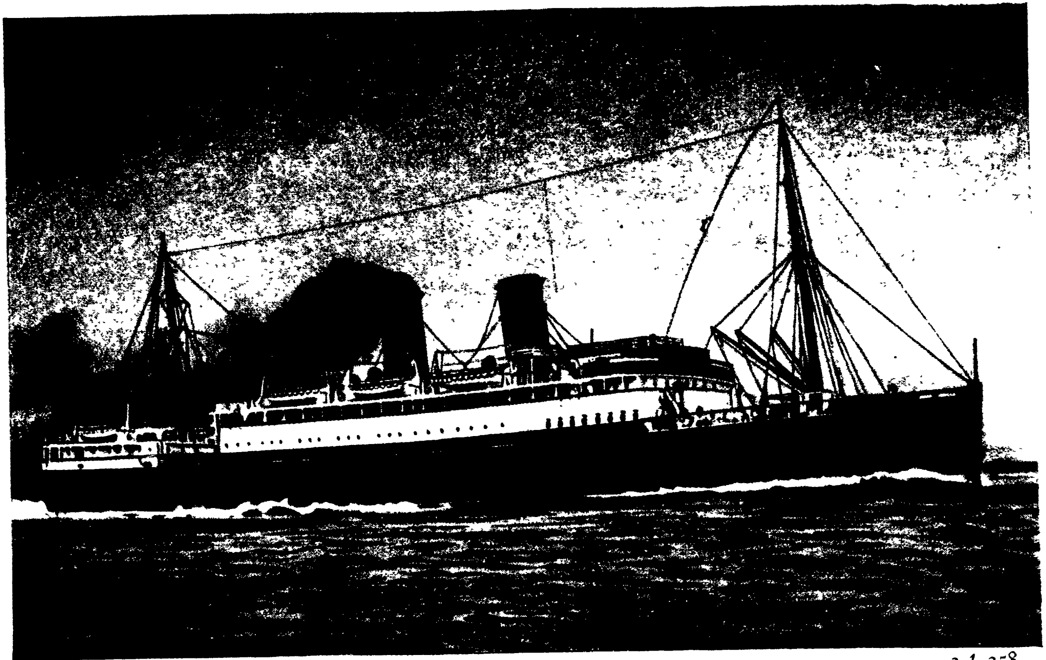
and restaurant-cars is done by the railways themselves. Beneath the Liverpool Street Station Hotel of the L.N.E.R., for example, there is an extensive bakery which has the reputation of making the finest Vienna bread in London, and has established it by securing many of the leading awards at bakery exhibitions.

In the matter of maritime passenger operations the Southern can probably claim the supremacy among British railways. Of the routes between England and the Continent, the all-important "short sea route"—21 miles in length—between Dover and Calais, and the Folkestone-Boulogne route, with their direct connections to all parts of Europe, are worked jointly by the Southern Railway and the Northern Railway of France; the Belgian National Railways operate their popular steamship services between Dover and Ostend; the Newhaven-Dieppe route, joint with the French State Railways, and the services from Southampton to Havre and St. Malo, are other Southern preserves. Beyond this, the rapid development of the port of Southampton is likely to be of immense value to the Southern Railway. The transfer of all the biggest American liners from Liverpool to Southampton is due to the fact that a start from Southampton makes it possible to include also a call at Cherbourg, without any material delay, in the route from England to the American ports; at Cherbourg is picked up the passenger traffic from Europe, much of which, before the war, was carried by the large German lines.

The London and North Eastern Railway is chiefly concerned with the traffic between England and the Northern countries of Europe, focussed on the Essex port of Harwich. Commodious accommodation has been established at Parkeston Quay (Plate 176), in a sheltered situation well up the estuary of the Stour, and from here daily services are worked by the L.N.E.R. to the Hook of Holland and to

the Belgian port of Antwerp, as well as by independent steamship companies to Flushing, in Holland, and Esbjerg, in Denmark. All parts of Northern and Central Europe are reached by through services in connection with these North Sea routes. Apart from Harwich, the L.N.E.R. is the owner of extensive dock and harbour accommodation all the way up the East Coast, in both England and Scotland ; the most important of the docks are those of the Humber, at Immingham and Grimsby (from which a regular passenger and cargo service is operated to Hamburg), on the south side of that river, and at Hull, on the north side. but the docks at Middlesbrough and Hartlepool, on the Tees, Tyne Dock and Blyth, on the Tyne, and Burntisland and Methil, on the Forth, are also very extensive. The principal business of these ports is that of coal export to Continental countries, although much manufactured material is also dealt with.

It was not until 1927 that the London, Midland and Scottish Railway entered seriously into the Continental passenger business by establishing, in conjunction with an independent steamship company, a route between Tilbury and Dunkirk, in France, with direct connections to Paris and Northern France generally. Like the L.N.E.R. routes from Harwich, this is a night service, comfortable cabin sleeping accommodation being provided on the boats in these cases. Tilbury has also of recent years become an important port of call for ocean liners which make use of the Port of London, saving passengers the tedium of the journey up and down the Thames between Tilbury and the London Docks. But the principal passenger services operated by the L.M.S. across the water are those between England and Ireland, which now number three routes in all—from Holyhead to Kingstown, or Dun Laoghaire, as it is now known ; from Heysham to Belfast, for the North



Pl. 177.

Turbine Steamer "Duke of Lancaster," Heysham-Belfast Service. L.M.S. (p. 359).

The purpose of the Great Western in their large expenditure on Fishguard was, however, to create a port for Transatlantic traffic, where the American liners might call on their way to and from Liverpool, thereby rendering possible a considerable curtailment in time of the journey to and from London, for which the G.W.R. provided some exceptionally rapid transport. For some time the largest Cunard steamers called at Fishguard in this way, but later on, for reasons already explained, the Cunard succumbed to the superior attractions of Southampton. The Great Western has of recent years obtained some compensation, however, by the practice of several of the Transatlantic lines in calling at Plymouth, whence non-stop trains bring the passengers and mails to London at high speed in but little over 4 hours. The fastest throughout times ever achieved from New York to London, by sea and rail, have been by Fishguard and by Plymouth. Certain ocean lines still call at Fishguard, and other lines, especially to and from the West Indies, use the Bristol port of Avonmouth, the Great Western providing the necessary railway facilities.

One other maritime development, with which railways are directly concerned, requires mention in this chapter. It is the method of establishing oversea railway communication by means of the train-ferry. The train-ferry provides a practical means of bridging large stretches of water, for railway purposes, by the simple expedient of carrying a length of railway track, with its freight of coaches or wagons, bodily across the water in a suitably-designed vessel.

Physical connection is made with the shore railway on one side of the water, in order to run the through vehicles on to the ferry, and at the conclusion of the sea journey communication is established, in the same way, with the tracks on the other side, enabling the coaches and wagons to be

run again on to land. Through train running across the water is in this way made possible, doing away with the delay arising out of the transhipment of passengers between train and boat, and especially with the labour of transhipping all the merchandise at both ends of the sea journey. It is in the carriage of freight that the train-ferry finds its maximum value. Not only is the through working of the consignments greatly speeded up, and practically all the usual port labour dispensed with, but the damage to consignments, which is almost invariably a serious feature of the transhipment, in the case of fragile goods, is eliminated.

In Europe, the western end of the Baltic Sea, with its many islands and water channels, is the scene of the most intensive train-ferry activity in the world. The little country of Denmark consists chiefly of islands, and in order to afford through railway communication between these islands, and also to and from the adjacent countries of Germany, Norway and Sweden, nine train-ferries are now in regular operation. The journey from London to Copenhagen, *via* Harwich and Esbjerg, involves the use of two of them, one across the Little Belt, 1¼ miles in length, and the other, 16 miles in length, across the Great Belt, on the railway trip from Esbjerg to Copenhagen. Other crossings of greater length are made between the German port of Warnemünde and Gjedser in Denmark, 28 miles in length, as well as from Sassnitz in Germany to Trelleborg in Sweden, the latter making possible the running of through express trains between Berlin and Stockholm and Oslo. Given a reasonably calm night, it is possible that the passenger who enters his comfortable sleeping berth in Berlin may awake on Swedish soil without the slightest realisation of having crossed 67 miles of sea during the night hours. Through running takes place similarly between Italy and Sicily by

a train-ferry across the Straits of Messina, linking Reggio, on the mainland, with the Sicilian town of Messina. In various parts of America use is also made of the train-ferry, particularly among the Great Lakes; between New Brunswick, Canada, and Prince Edward Island (where, owing to the low winter temperatures it is necessary to employ a powerful ice-breaking ferry-steamer for the 9-mile crossing); and over certain sea channels in the neighbourhood of San Francisco. The Southern Pacific Railway, which operates those last-mentioned, owns some very large train-ferry steamers, on which not only the trains, but also their long-distance locomotives, are accommodated (Plate 178). In Plate 180 is seen the important Oakland Pier terminal of the latter railway: this is situated on the east side of San Francisco Bay, and is connected with San Francisco by a busy ferry service, as well as by a train-ferry, the berth for which is seen on the extreme left-hand side of the photograph. The largest train-ferry in the world is also American, though British-built. Aptly named the "Seatrain," it plies between New Orleans and Cuba—a 52-hour voyage. On three decks the "Seatrain," which is 427 ft. long and has a tonnage of 10,500, can accommodate from 90 to 95 American high-capacity bogie wagons.

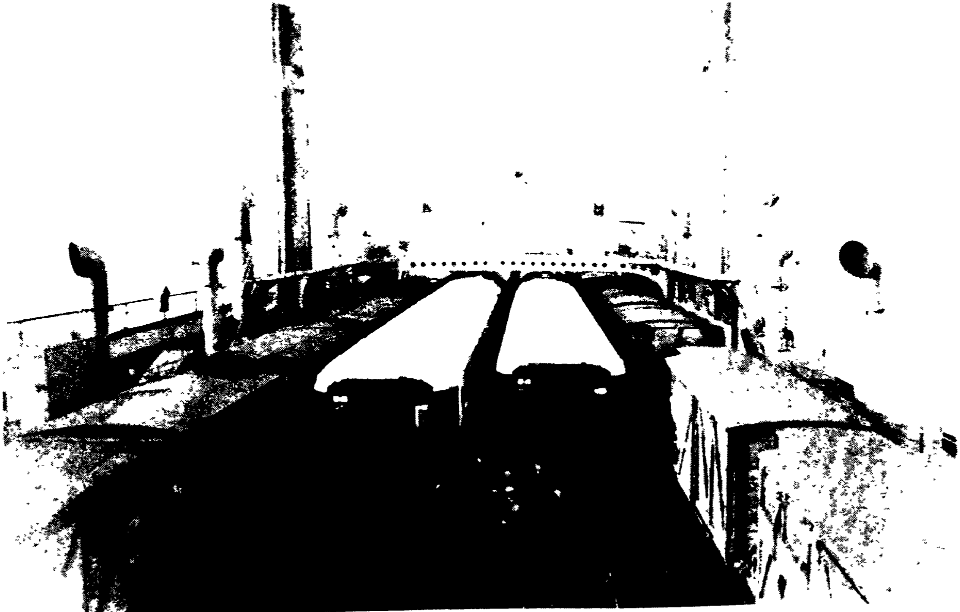
The earliest British train-ferries were those which crossed the Firths of Forth and Tay, from Granton to Burntisland and Tayport to Broughty Ferry respectively, prior to the opening of the Forth and Tay Bridges. These were of a primitive type, carrying goods wagons only, and fell into disuse after the direct rail communication became available. Not until the Great War did the train-ferry become re-established in this country. It was the realization of the vast saving of labour which would result from the through working of munitions from their source of origin right up to the Western front that led to the establishment of train-

ferry services between Richborough in Kent, and the French port of Dunkirk, and between Southampton and Havre. Both these went out of use after the war, but the advantages of through working were too great to be abandoned, and a permanent train-ferry service, worked with certain of the vessels from these war routes, is now operating nightly between Harwich, in Essex, and the famous Belgian port of Zeebrugge. Each of the ferry-steamers employed is provided with four lines of rails, accommodating a total of 54 wagons

Special wagons are used by the train-ferry service (which is a private company, although the L.N.E.R. is actually responsible for the working); these are of the usual Continental type, somewhat limited in width in order to pass the British loading gauge, and provided with thin flanges to their wheel-tyres, the extra ½-inch in the width of the track gauge abroad, as compared with the British, creating slight difficulties in regard to the passage of standard British flanges through the check-rails of Continental crossings. To allow for the rise and fall of the ferry-steamer with the tide, when berthed, communication with the shore lines is made by means of a hinged bridge, over which the wagons are run on and off the vessel. On board they are securely shackled for their sea journey; in this connection it is worthy of note that, despite the extreme roughness of the North Sea at times, not a journey has yet been missed by the ferry-steamer in either direction, nor have there been any casualties to the wagons carried across.

Many interesting facts could be mentioned in connection with this ferry service. It is beyond question that definite lines of trade have been established, while other lost trades have been regained, by its use. Among the latter may be mentioned the best-class pottery work, packed in wagons at the works in the Potteries, and carried through to destina-

tions all over Europe, without fear of breakage. Fruit is brought in through train-ferry wagons from Italy and the South of France to England, and, by way of exchange, some of the abundant catches of sea-water fish from our East Coast is passed down into Italy and elsewhere, all without handling intermediately, and in a minimum of time, both of which are considerations of prime importance in the handling of foodstuffs. The majority of the magnificent Pullman, sleeping and dining cars built in this country for Continental use have crossed by means of Harwich-Zeebrugge ferry (Plate 179), and by way of exchange a large traffic in motor-cars, conveyed in specially-built covered wagons, passes from Milan and Turin to London by the same route. It need thus be a matter of no surprise that the traffic by the Harwich-Zeebrugge train-ferry has been unceasingly on the increase from its opening until the present time.



Pl. 179. 2 A 364

Harwich-Zeebrugge Train-Ferry Steamer Interior (p 363).

In addition to the train-ferry freight wagons, British-built Pullman cars are being carried across the North Sea for service on the Continent

Pl. 18c. [illegible] 365.

Oakland Pier Terminal, Southern Pacific Railway, U.S.A. (p. 362).

The train-ferry berth is seen on extreme left of photograph.

CHAPTER XX

Administration

By comparison with the technical aspects of railway construction, equipment and working, the question of administration may to the average reader seem a somewhat dry subject for discussion, but the methods adopted must be briefly referred to, if our survey of the railway is to be complete. The task of supervising the operations of one of our large railway groups is one of an immensity but little realized by the man in the street. The four great British railways—the London, Midland and Scottish, the London and North Eastern, the Great Western and the Southern, in their order of size—employ between them 671,500 men, and pay out in wages over one hundred millions sterling annually. On their tracks the gross capital expenditure to date has been 810 millions ; on their rolling stock 145 millions ; and on machinery, plant, buildings, docks, steamboats, electric power stations, and many other items of equipment, something like 160 millions ; the gross annual income derived from working amounts to 220 millions, but of this sum between 170 and 180 millions vanish in working expenses. The direction of such vast concerns is therefore a matter of no small difficulty and complexity.

The shareholders of the " Big Four " number 784,000, of whom it is estimated that 480,000 possess holdings of £500 or less. Appointed by them to watch their interests are the Boards of Directors, to whom the railway officers, headed in each case by the General Manager—or the Chief

General Manager, as the chief executive officer is known on the L.N.E.R.—are responsible. Among British railways it is only on the London, Midland and Scottish and the London Electric Railway group that this arrangement is varied by giving the chief of the executive a seat on the Board. On the L.M.S. system his title is President of the Executive, to which, in the case of Sir Josiah Stamp, is now added the dignity of Chairman of Directors ; on the London Electric system Lord Ashfield is known as Managing Director, with the same function. The L.M.S. Company has largely followed the American method by the appointment of four Vice-Presidents, who, with the President, the Secretary and the Chief Legal Adviser, form an executive committee for the railway. There are two Vice-Presidents representing the operating side of the railway, one the accounting side, and one the technical side, including works and rolling stock.

The London and North Eastern method differs entirely from this. The railway, which by its geographical lay-out lends itself admirably to the plan, has been divided into three "areas." The Southern Area comprises the old Great Eastern, Great Northern and Great Central systems ; the North Eastern Area is virtually the complete one-time North Eastern Railway, with the small Hull and Barnsley system added ; the Scottish Area is the whole of the lines north of the Border, comprising the North British and Great North of Scotland systems. Each of these areas has its own Divisional General Manager, responsible to the Chief General Manager in London. Each has also its own Chief Civil Engineer, charged with the maintenance of track and structures ; but in regard to rolling stock there is one Chief Mechanical Engineer for the whole railway, with Assistant Mechanical Engineers in charge of the two main locomotive, carriage and wagon building works, at Doncaster and

Darlington, and Divisional Mechanical Engineers responsible for the other three chief locomotive works—at Stratford (London), Gorton (Manchester) and Cowlairs (Glasgow)—whose work is now confined mainly to the execution of heavy repairs. The Great Western and Southern Railways, with their more compact territory, lend themselves more readily to the same type of organization as that of their constituent companies prior to the amalgamation; their chief officers in both cases, from the General Manager downwards, supervise the operations of the whole of their respective systems.

A few words must be said, in conclusion, concerning the work of each department of the railway. All the major matters of policy are vested in the Chief General Manager, whose department is therefore the focus of the railway administration; this department forms the main channel of communication between the Directors and the staff; and it is also the medium whereby touch is maintained between the railway and the public. It is for this reason that the publicity work of the railway—both in the matter of advertising and of information for the Press—is on the L.N.E. and Southern Railways under the immediate control of the General Manager's Department. The extent of modern railway advertising may well be realized by the fact that in any normal year the "Big Four" between them advertise regularly in more than one thousand newspapers, use nearly a quarter of a million spaces on hoardings and elsewhere for constant poster display, and issue eight million holiday and travel booklets of various kinds

The Secretary of the railway, as in the case of all public companies, is the keeper of its official records, and is responsible as a link between the General Manager and the Chairman of Directors in the handling of the statutory annual meetings of shareholders. The complex business of keeping the accounts and paying the bills of the railway is

department. On the London, Midland and Scottish Railway for example, the working of locomotives is in charge of the Superintendent of Motive Power—a title of American origin—and forms part of the activities of the General Superintendent's Department. On the Southern and on the London and North Eastern Railways, however, locomotive running is entirely separated from locomotive building and maintenance. It is in consequence of this development that the title of the officer responsible for the design and construction of locomotives and rolling stock has now generally changed from "Locomotive Superintendent," or the cumbrous "Locomotive, Carriage and Wagon Superintendent," to the more suitable appellation of "Chief Mechanical Engineer." Even this limitation of his duties leaves the official concerned with enormous responsibilities. The Chief Mechanical Engineer of the L.M.S., for example, is charged with the upkeep of 10,160 locomotives, 6,900 tenders, 27,200 coaching vehicles and 330,000 wagons.

Hitherto the Chief Mechanical Engineers have been largely responsible for electrical matters, but the rapidly increasing scope of electrical equipment, especially on lines where electrical working of trains has been brought into use, calls for the appointment of an independent Electrical Engineer, which has been made on the L.M.S., and Southern Railways. On the London and North Eastern and Great Western Railways, the Electrical Engineers are under the jurisdiction of the Chief Mechanical Engineers, as heretofore.

The four great groups differ widely from each other in their operating arrangements. The London and North Eastern Railway has, for each of its three areas, a Superintendent, a Passenger Manager and a Goods Manager, the first-mentioned being responsible for the actual supervision of the operating staff, the time-tables, and the working of the trains generally, the second for the commercial side of the passenger, parcels

and mail services, and the third for the corresponding work in connection with the movement of freight. For greater attention to detail, the three larger areas are divided up into smaller districts, each with its own District Superintendent, Passenger Manager and Goods Manager, the two last-mentioned posts being in some cases undertaken by one official. The Great Western Railway combines the administration of the Superintendent's and Passenger Manager's Departments under one Superintendent of the Line, who is also responsible for publicity work, but there is an independent Goods Manager. On the Southern, again, there is a Chief Operating and a Chief Commercial Manager, corresponding somewhat in their respective functions with the two Great Western officials just mentioned.

The London, Midland and Scottish operating organization is rather more complex in character. Over all operating matters is appointed the Chief General Superintendent, whose office is located in a central position on the system, at Derby; here, in pre-grouping days, were found the General Offices of the late Midland Railway. Under this officer are Divisional Superintendents, with offices at Euston, Derby, Manchester and Glasgow, responsible respectively for the late London and North Western, Midland, Lancashire and Yorkshire and Scottish sections of this great system, now known as the Western, Midland, Central, and Scottish Divisions. Under the Chief General Superintendent also is a Passenger Commercial Superintendent, supervising in his turn Divisional Passenger Commercial Superintendents. Lastly, included in the scope of this comprehensive Department, there is the Superintendent of Motive Power, previously mentioned, with divisional representatives at Crewe, Manchester, Derby and Glasgow. Freight matters are handled by an independent Chief Goods Manager, under whom are a Goods Operating Manager and a Goods Com-

mercial Manager, while there is, further, a Mineral Manager for the system, with offices at Derby.

Among other branches of railway organization, with its extraordinary ramifications, mention must be made of the Continental Departments of the London and North Eastern and the Southern Railways, with their important responsibilities. Marine activities are controlled by a Chief Marine Superintendent on the L.M.S., and a Docks and Marine Manager on the Southern; the Great Western has a Chief Docks Manager, located in the centre of the Welsh ports, at Cardiff. Then, again, there is the Stores Superintendent of each railway, charged with the duty of effecting the purchase of all stores required by the various departments for the working of the railway; the scope of his duties may be realized when it is mentioned that the four largest groups purchase collectively, in each year, something like 16 million tons of coal, 17 million cubic feet of timber, 21 million bricks, nearly four million yards of cloth for uniforms, four million sleepers, 300,000 tons of miscellaneous steelwork, well over 200,000 tons of steel rails, and other materials in huge quantities and almost infinite variety. Then there are the departments of Hotels, Refreshment Rooms and Restaurant Cars, referred to in the last chapter. Police Departments, Horse and Motor Departments, and other departments of lesser size and scope, far too numerous to mention

Running a railway is thus a colossal and a complicated business. That railway operation and management has reached a state of perfection no one would venture to claim—and least of all, probably, the railways themselves; but it may certainly be contended that in Great Britain—the birthplace of the railway, but little over a century ago—the science of railroading has reached a very high stage of development. It has been said that railways set the pace of

industrial development, and it is certain that the cheap and efficient transport that they have afforded is in large measure the secret of the remarkable industrial progress of Great Britain during the past hundred years. For the transport of heavy freight in bulk neither the roads nor the air can ever supplant the railways; nor is it likely that for rapid and inexpensive movement of passengers in large numbers any substitute for the railways will be found. The evolution, equipment and working of our railways are therefore fruitful subjects for study, and if this little volume should prove of value to the reader in elucidating his railway problems, and in stimulating his railway interest, the author will feel more than satisfied with the results of his work.

APPENDIX A

Highest Altitudes on British Railways

Height above sea level	Railway	Summit	Route
Feet			
3,140	Snowdon Mountain Tramway	Snowdon Summit	——
1,484	L.M.S. (Highland Section)	Drumochter	Main Line, Perth—Aviemore
1,474	L.N.E.R. (N.E. Section)	Parkhead	Burnhill—Stanhope Branch
1,405	L.M.S. (Caledonian Section)	Leadhills	Wanlockhead Branch
1,400	,, (Western "A" Section)	Waen Avon	Bryn Mawr—Pontypool
1,373	G.W.R.	Princetown	Princetown Branch
1,370	L.N.E.R. (N.E. Section)	Bloweth Summit	Rosedale Mineral Branch
1,369	L.N.E.R. (N.E. Section)	Stainmore	Darlington—Kirkby Stephen
1,350	,, (N.B. Section)	Corrour	Crianlarich—Fort William
1,315	L.M.S. (Highland Section)	Slochd Mhuic	Aviemore—Inverness (direct)
1,314	G.W.R. (Brecon & Merthyr)	Dowlais Top	Newport—Brecon
1,216	L.M.S. (Western "A" Section)	Nantybwch	Abergavenny—Merthyr
1,192	,, ,, ,, ,,	Hindlow	Buxton—Ashbourne
1,170	L.N.E.R. (N.E. Section)	Burnhill Jct.	Darlington—Blackhill
1,167	L.M.S. (Midland Section)	Ais Gill	Main Line, Leeds—Carlisle
1,100	L.N.E.R. (N.E. Section)	Wearhead	Wearhead Branch
1,052	L.M.S. (Highland Section)	Dava	Aviemore—Forres
1,014	,, (Caledonian Section)	Beattock Summit	Main Line, Carlisle—Glasgow

APPENDIX B

THE WORLD'S HIGHEST RAILWAY SUMMITS

Height above sea level	Railway	Summit	Route	Gauge of Railway	Notes
Feet				ft. ins.	
15,834	Antofagasta (Chili) & Bolivia	Montt	Callahuasi Branch	2 6	A
15,814	,, ,, ,,	Condor	Potosi Branch	3 3⅜	A
15,806	Central Railway of Peru	La Cima	Maracogha Branch	4 8½	A
15,694	,, ,, ,,	Galera Tunnel	Lima—Oroya	,,	A
14,668	Southern ,, ,,	Crucero Alto	Arequipa—Cuzco	,,	A
14,147	Pike's Peak (U.S.A.)	Pike's Peak	(Summit)	,,	R
13,061	Antofagasta (Chili) & Bolivia	Kenko	La Paz Branch	3 3⅜	A
12,976	,, ,, ,,	Ascotan	Antofagasta—Ollague	3 3⅜	A
12,000	Guayaquil & Quito	—	—	3 6	A
11,340	Jungfrau (Switzerland)	Jungfraujoch	(Summit)	3 3⅜	RAE
11,330	Denver & Rio Grande (U.S.A.)	Fremont Pass	—	4 8½	A
10,856	,, ,, ,,	Marshall Pass	Denver—Salt Lake City	,,	A
10,512	Transandine	Caracoles	Mendoza—Los Andes	3 3⅜	RA
10,248	Rio Grande Southern (U.S.A.)	Lizard Head	Ridgway—Durango	4 8½	A
10,236	Gorner Grat (Switzerland)	Gornergrat	(Summit)	3 3⅜	RE

A: Worked by Adhesion. R: Worked by Rack-and-Pinion. RA: Combined Rack and Adhesion. E: Electrically-operated.

APPENDIX C

The Longest Railway Tunnels in the World

Name	Length	From	To	Country	Route
	Miles				
Simplon	12·3	Brigue	Iselle	Switzerland-Italy	Lausanne–Milan
Apennine	11·5	Castiglione	Vernio	Italy	Bologna–Florence
St. Gotthard	9·3	Göschenen	Airolo	Switzerland	Lucerne–Milan
Lötschberg	9·1	Kandersteg	Goppenstein	,,	Berne–Brigue
Mont Cenis	8·0	Modane	Bardonecchia	France–Italy	Dijon–Turin
Cascade	7·8	Scenic	Berne	United States	Seattle–Spokane
Arlberg	6·4	St. Anton	Klosterle	Austria	Zurich–Innsbrück
Moffat	6·1	Tolland	Fraser	United States	Denver–Craig†
Tavern	5·5	Bad Gastein	Mollnitz	Austria	Salzburg–Trieste
Ricken	5·3	Wattwil	Kaltbrunn	Switzerland	Zurich–St. Gallen
Grenchenburg	5·3	Moutier	Granges	,,	Basle–Neuchatel

Otira	5·3	Avoca	Otira	New Zealand	Christchurch–Greymouth
Hauenstein	5·1	Tecknau	Olten	Switzerland	Basle–Lucerne
Somport	5·0	Forges d'Abel	Canfranc	France–Spain	Pau–Saragossa
Connaught	5·0	Beavermouth	Glacier	Canada	Calgary–Vancouver
Monte Orso	4·7	Fondi	Itri	Italy	Bologna–Florence
Hoosac	4·7	Hoosac Tunnel	North Adams	United States	Boston–Albany
Monte Adone	4·5	S. Ruffilo	Vardo	Italy	Rome–Naples
Severn	4·4	Pilning	Severn Tun. Jc.	England	London–S. Wales
Jungfraujoch	4·3	Eigergletscher	Jungfraujoch	Switzerland	Scheidegg–Jungfraujoch

† To be extended ultimately to Salt Lake City.

Note.—Trains on the Edgware-Morden service of the Underground Electric Railways of London travel for 14 miles continuously in tunnel, this being strictly the longest tunnel in the world.

APPENDIX D

Longest British Railway Tunnels

Name	Railway	Stations between		Route	Length	
					miles	yards
Severn	G.W.R.	Pilning	Severn Tun. Jc.	South Wales main line	4	624
Totley	L.M.S.	Dore	Grindleford	Sheffield–Manchester	3	950
Standedge†	,,	Marsden	Diggle	Huddersfield–Manchester	3	57
Woodhead§	L.N.E.R.	Woodhead	Dunford Bridge	Sheffield–Manchester	3	13
Sodbury	G.W.R.	Badminton	Sodbury	South Wales main line	2	913
Disley	L.M.S.	Chinley	Cheadle Heath	Derby–Manchester	2	346
Bramhope	L.N.E.R.	Horsforth	Arthington	Leeds–Harrogate	2	234
Festiniog*	L.M.S.	Roman Bridge	Festiniog	Llandudno–Festiniog	2	206
Cowburn	L.M.S.	Edale	Chinley	Sheffield–Manchester	2	182
Sevenoaks	S.R.	Sevenoaks	Hildenborough	London–Tonbridge	1	1691
Rhondda*	G.W.R.	Treherbert	Cymmer	Treherbert–Swansea	1	1683
Morley	L.M.S.	Morley	Batley	Leeds-Huddersfield	1	1590

Box	G.W.R.	Corsham	Box	Swindon–Bath	1	1452
Catesby	L.N.E.R.	Charwelton	Braunston	Marylebone–Leicester	1	1237
Dove Holes	L.M.S.	Peak Forest	Chinley	Derby–Manchester	1	1224
Littleborough	L.M.S.	Walsden	Littleborough	Halifax–Manchester	1	1125
Waterloo	L.M.S.	Edge Hill‡	Riverside‡	Riverside Branch	1	1000
Ponsbourne	L.N.E.R.	Cuffley	Bayford	Wood Green–Hertford	1	924
Bolsover	„	Scarcliffe	Bolsover	Lincoln–Chesterfield	1	864
Polhill	S.R.	Knockholt	Dunton Green	London–Tonbridge	1	849
Queensbury	L.N.E.R.	Queensbury	Holmfield	Bradford–Halifax	1	741
Merthyr*	G.W.R.	Merthyr	Abernant	Merthyr–Swansea	1	735
Kilsby	L.M.S.	Welton	Rugby	Euston–Crewe	1	666
Blea Moor	„	Ribbiehead	Dent	Leeds–Carlisle	1	629
Shepherd's Well	S.R.	Shepherd's Well	Kearsney	Canterbury–Dover	1	605

All above are double-line tunnels except the following :—

† Four lines (three parallel tunnels).
§ Two lines (two parallel tunnels).
* Single line.
‡ Liverpool.

APPENDIX E

Locomotive Wheel Arrangements

British and American Notation	American Class Name	French Notation	German Notation	Service on which generally employed
TENDER	ENGINES.			
2–2–2	Jenny Lind	1–1–1	1–A–1	Express Passenger (obsolete)
4–2–2	Single-driver	2–1–1	2–A–1	,, ,, ,,
4–4–0	American	2–2–0	2–B	,, ,,
*2–4–2	Columbian	1–2–1	1–B–1	,, ,, (rare)
4–4–2	Atlantic	2–2–1	2–B–1	,, ,,
*4–4–4	Reading	2–2–2	2–B–2	,, ,, (rare)
0–6–0	—	0–3–0	C	Intermediate Freight
2–6–0	Mogul	1–3–0	1–C	Slow Pass. and Express Freight
4–6–0	American	2–3–0	2–C	Express Pass. and Express Freight
*2–6–2	Prairie	1–3–1	1–C–1	Express Passenger
4–6–2	Pacific	2–3–1	2–C–1	Express Passenger
*2–6–4	Adriatic	1–3–2	1–C–2	,, ,, (rare)
*4–6–4	Baltic or Hudson	2–3–2	2–C–2	,, ,, (rare)
0–8–0	—	0–4–0	D	Heavy Freight
2–8–0	Consolidation	1–4–0	1–D	,, ,,
2–8–2	Mikado	1–4–1	1–D–1	,, ,,
*4–8–2	Mountain	2–4–1	2–D–1	Fast and Heavy Passenger
*4–8–4	Confederation	2–4–2	2–D–2	,, ,, ,,

0–10–0	Decapod	0–5–0	E	Heavy Freight (rare)
*2–10–0	—	1–5–0	1–E	,, ,, ,,
*4–10–0	Mastodon	2–5–0	2–E	,, ,, ,,
*2–10–2	Santa Fe	1–5–1	1–E–1	,, ,, ,,
*4–10–2	—	2–5–1	2–E–1	,, ,, ,,
*2–12–0	Centipede	1–6–0	1–F	,, ,, ,,
*4–12–2	—	2–6–1	2–F–1	,, ,, ,,
TANK ENGINES (CHIEFLY BRITISH).				
0–4–0T	—	0–2–0	B	Light shunting
0–4–4T	—	0–2–2	B–2	Suburban passenger
4–4–0T	—	2–2–0	2–B	,, ,, (rare)
2–4–2T	—	1–2–1	1–B–1	,, ,,
4–4–2T	—	2–2–1	2–B–1	,, ,,
0–6–0T	—	0–3–0	C	Shunting
0–6–2T	—	0–3–1	C–1	Suburban Passenger and Freight
2–6–2T	—	1–3–1	1–C–1	Short-distance Passenger and Freight
4–6–2T	—	2–3–1	2–C–1	Short-distance Exp. Passenger
0–6–4T	—	0–3–2	C–2	Suburban Passenger
2–6–4T	—	1–3–2	1–C–2	Short-distance Exp. Pass. and Freight
4–6–4T	—	2–3–2	2–C–2	Express Passenger
0–8–0T	—	0–4–0	D	Short-distance Freight
2–8–0T	—	1–4–0	1–D	,, ,, ,,
0–8–2T	—	0–4–1	D–1	Marshalling Sidings
4–8–0T	—	2–4–0	2–D	,, ,, (rare)
0–8–4T	—	0–4–2	D–1	,, ,,

* Not used in Great Britain.

APPENDIX F

Leading Dimensions of Principal British Express Locomotive types

Railway	Wheel arrangement	Clas	Cylinder No.	Cylinder Dia.	Cylinder Stroke	Driving wheels Dia.	Total heating Surface	Fire-grate Area	Working steam Pressure	Tractive Effort at 85% working Pressure	Weight in working order: Adhesion	Weight in working order: Total Engine	Weight in working order: Engine and tender
				in.	in.	ft. in.	Sq. ft.	Sq. ft.	lb. per sq. in.	lb.	tons	tons	tons
L.N.E.R.	4-6-2	Super-"Pacific" *	3	19	26	6 8	3,443	41·3	220	32,910	66¼	96¼	152¾†
,,	4-4-2	G.N. type	2	20	24	6 8	2,449	31·0	170	17,360	40	69½	112½
,,	,,	N.E. ,, ("Z")	3	16½	26	6 10	2,509	27·0	180	19,810	40	77	122½
,,	,,	N.B. ,,	2	21	28	6 9	2,189	28·5	180	23,325	40	76½	122
,,	4-6-0	"Sandringham"	3	17½	26	6 8	2,020	27·5	200	24,380	53¾	76¾	116
,,	4-4-0	"Shire" type	3	17	26	6 8	1,644	26·0	180	21,555	42	66	118¾
,,	4-4-0	"Director" ,,	2	20	26	6 9	1,752	26·5	180	19,650	39¾	01	109½

L.M.S.	4-6-0	" Royal Scot "	3	18	26	6	9	2,526	31·2	250	33,150	62½	85	127¾
"	"	" Claughton "†‡	4	15¾	26	6	9	2,098	30·5	200	27,070	59½	79	119¾
"	"	" Prince "	2	20½	26	6	3	1,898	27·0	175	21,670	46¾	66¼	102½
"	4-4-0	Compound	1 H.P. 2 L.P.	19 21	26	6	9½	1,608	28·4	200	24,065	39¼	61¾	104½
"	"	" George V "	2	20½	26	6	9	1,849	22·4	175	20,065	38	59¾	96
G.W.R.	4-6-0	" King Geo. V "	4	16¼	28	6	6	2,514	34·3	250	40,300	67½	89	135¾
"	"	" Castle "	4	16	26	6	8½	2,312	30·3	225	31,625	58¾	79¾	126½
"	"	" Star "	4	15	26	6	8½	2,125	27·0	225	27,800	55½	75½	115½
"	"	" Saint "	2	18½	30	6	8½	2,125	27·0	225	24,550	50¼	72	112
"	4-4-0	" County "	2	18	30	6	8½	1,567	20·5	200	20,525	37½	58¾	98¾
S.R.	4-6-0	" Lord Nelson "	4	16½	26	6	7	2,365	33·0	220	33,510	62	83½	140¼
"	"	" King Arthur "	2	20½	28	6	7	2,215	30·0	200	25,450	60	81	138½
"	4-4-0	Improved " L "	2	19½	26	6	8	1,642	22·5	180	18,885	38	58½	99

* The remaining engines (" Flying Scotsman " type) have cylinders 20 in. diameter, a working pressure of 180 lb. per sq. in., and a tractive effort of 29,835 lb. † With corridor tender. ‡ Rebuilt type.

APPENDIX G

The Longest Daily Non-stop Railway Runs in Great Britain

(From the 1928 Time-Tables)

Railway	Between	Distance	Fastest Daily Train			Total No. of runs daily
			Time	Average speed	Name of Train	
		Miles	Min.	m.p.h.		
L.N.E.R.	*King's Cross—Edinburgh	392·7	495	47·6	" Flying Scotsman "	2 (*s*)
L.M.S.	*Euston—Carlisle (Kingmoor)	300·8	347	52·0	" Royal Scot "	1 (*s*)
,,	Carlisle No. 12 Box—Euston*	298·2	353	50·7	,, ,,	1 (*s*)
,,	Glasgow—Crewe	243·2	320	45·6	" Night Scot "	1
G.W.R.	*Paddington—Plymouth	225·7	240	56·4	" Cornish Riviera " Exp.	2 (*s*)
L.M.S.	*Euston—Prestatyn	205·5	238	51·8	" Welshman "	1 (*s*)
G.W.R.	*Paddington—Torquay	199·7	210	57·1	" Torbay Limited "	2 (*s*)
,,	Newton Abbot—Paddington*	193·9	205	56·8	,, ,,	1 (*w*)
L.M.S.	*Euston—Liverpool†	189·7	206	55·3	"London-Merseyside" Exp.	1
L.N.E.R.	*King's Cross—York	188·2	210	53·8	" Scarborough Flyer "	2 (*s*)
,,	*King's Cross—Leeds	185·7	205	54·3	" Queen of Scots " Pullman	2
L.M.S.	*Euston—Wilmslow	176·9	187	56·8	" Mancunian "	2
L.N.E.R.	*King's Cross—Wakefield	175·8	183	57·6	" West Riding " Pullman	2

G.W.R.	*Paddington—Exeter	173·7	173	60·2	" Cornish Riviera " Exp.	3 (*a*)
L.M.S.	Crewe—Broad St.*	162·4	216	45·1	Express Fish Train	1
"	Prestatyn—Bletchley	158·8	187	50·9	" Welshman "	1 (*s*)
"	*Euston—Crewe	158·1	169	56·0	Newspaper Express	16
"	Kingmoor (Carlisle)—Perth	149·0	199	44·9	" Royal Highlander "	1 (*s*)
"	Chesterfield—St. Pancras*	146·3	165	53·2	12.55 p.m. ex Leeds	1
"	Stoke-on-Trent—Euston*	145·9	161	54·4	" Lancastrian "	1
G.W.R.	Greenford—Shrewsbury	145·1	223	39·0	Express Freight Train	1
G.W.R.	*Paddington—Taunton	142·9	148	57·9	7.5 a.m. ex Plymouth	4
L.M.S.	Crewe—Kingmoor (Carlisle)	142·7	174	49·2	" Royal Highlander "	1 (*s*)
G.W.R.	Newbury Racecourse—Newton Abbot	141·5	211	40·2	Express Freight Train	1
L.M.S.	Crewe—Carlisle	141·0	164	51·7	10.7 a.m. ex Euston	12
"	*Euston—Stafford	133·6	145	55·3	11.10 a.m. ex Liverpool	4
G.W.R.	Paddington—Newport	133·4	140	57·2	3.55 p.m. ex Paddington	6
L.N.E.R.	*Liverpool St.—N. Walsham	130·2	159	49·1	" Norfolk Coast Express "	2 (*s*)

* London. † Mossley Hill Station. (*s*) Summer Service only. (*w*) Winter service only.
(*a*) The " Cornish Riviera " Express calls at Exeter in winter only: fastest summer time 180 min. = 57.9 m.p.h.

APPENDIX I

Fastest Daily Railway Runs in France

(From the Summer Time-Tables, 1928)

Railway	Train Nos.	Between	Distance	Fastest Train		
				Time	Speed	Name
			Miles	Min.	M.p.h.	
Nord	185	Paris–St. Quentin	95·1	92	62·0	Nord Express
Midi	41	Bordeaux–Dax	91·7	89	61·8	Sud Express
”	71	” ”	91·7	91	60·5	—
Nord	173	Paris–Lille	156·0	155	60·4	Ostend Pullman
”	5	Paris–Etaples	140·9	140	60·4	Calais Boat Express
”	115	Paris–St. Quentin	95·1	95	60·1	—
”	109, 123, 179	Paris-Aulnoye	134·0	135	59·6	—
”	1280, 1284	Etaples–Amiens	59·5	60	59·5	—
”	307, 317	Paris–Arras	119·4	121	59·2	—
”	180	Jeumont–Paris	147·9	150	59·2	Nord Express
Midi	72	Dax-Bordeaux	91·7	93	59·2	Sud Express

Nord	7	Paris–Etaples	140·9	143	59·1	Boulogne Boat Exp.
”	69	Le Landy–Amiens	78·8	80	59·1	—
”	138	Tergnier–Compiègne	29·5	30	59·0	—
”	122	St. Quentin–Paris	95·1	97	58·8	—
”	165	Paris–Compiègne	51·9	53	58·7	—
”	304, 306	Arras–Longueau	41·1	42	58·7	—
”	1289	Amiens–Etaples	59·5	61	58·5	—
”	172	Lille–Paris	156·0	160	58·5	Ostend Pullman
Est	31	Paris–Troyes	103·3	106	58·5	Basle Express
Nord	112	Aulnoye–St. Quentin	38·9	40	58·4	—
”	99	Le Landy–Amiens	78·8	81	58·4	—
Midi	41	Dax Bayonne	31·1	32	58·3	Sud Express
Nord	78, 79	Paris–Calais	184·5	190	58·3	“ Golden Arrow ” Pullman
”	112	St. Quentin–Paris	95·1	98	58·2	—
”	309	Paris–Arras	119·4	123	58·2	—

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